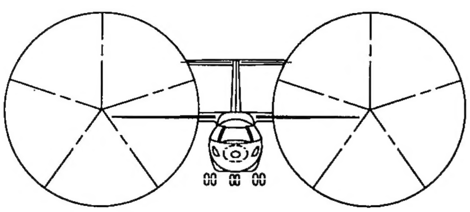
Civil Tiltrotor Development Advisory Committee

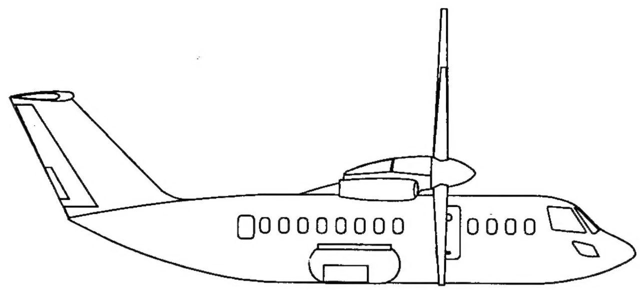
Report to Congress

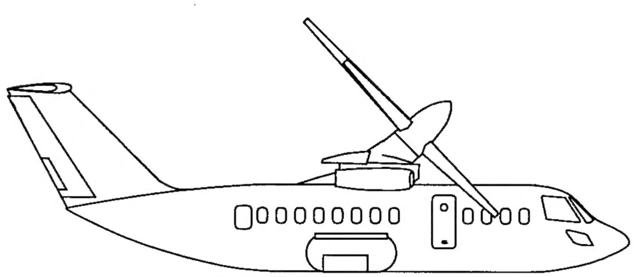
in accordance with PL102-581

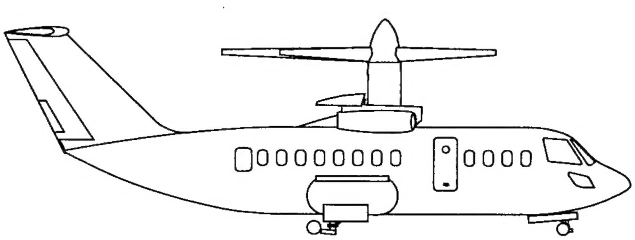
Volume 2
Technical Supplement

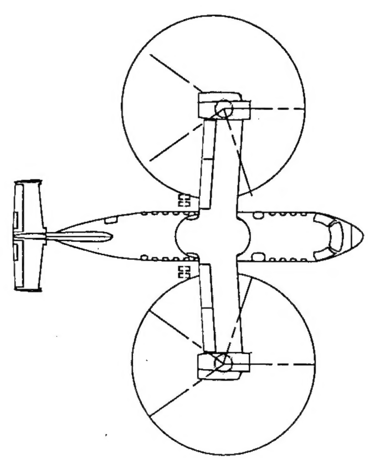
December 1995











This report represents the work of the Civil Tiltrotor Development Advisory Committee established as required by the Airport and Airway Safety, Capacity, Noise Improvement, and Intermodal Transportation Act of 1992. As such, the report reflects the views of the Committee membership and should not be interpreted as representing the official position of the Administration.

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16. Abstract

Under public law (PL102-581), the U.S. Congress directed the Secretary of Transportation to establish a Civil Tiltrotor Development Advisory Committee (CTRDAC). The committee was directed to examine the costs, technical feasibility, and economic viability of developing civil tiltrotor (CTR) aircraft.

The CTRDAC found that the CTR is technically feasible, that it could be economically viable and operate profitable without government subsidies in heavily traveled corridors, and that it could provide significant societal benefits.

The CTRDAC recommended that a public/private partnership be created to address CTR institutional, infrastructure, and coordination issues; that an integrated aircraft and infrastructure research, development, and demonstration program be conducted over 10 years with $600 million in Government/industry cost sharing; and that work be accelerated on regulatory and certification issues, including safety and environmental standards and changes in the air traffic control system.

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Foreword

The Airport and Airway Safety, Capacity, Noise Improvement, and Intermodal Transportation Act of 1992 (PL102-581, Section 135) directed the U.S. Department of Transportation Secretary to establish a Civil Tiltrotor Development Advisory Committee (CTRDAC). The committee was directed to examine the (1) costs, technical feasibility, and economic viability of developing civil tiltrotor (CTR) aircraft, (2) benefits to the national economy, (3) further research and development requirements, (4) changes to regulatory standards, and (5) which costs should be financed by the Government and which by the private sector. The CTRDAC was further charged to deliver to Congress a report containing determinations and recommendations on the five points listed above.

The membership of the CTRDAC is shown below.

Frank E. Kruesi
Chair, CTRDAC
Assistant Secretary for Transportation Policy
U.S. Department of Transportation

Robert Baker
Executive Vice President for Operations
American Airlines, Inc.

Helane Becker-Roukas
Vice President, Smith Barney

Stanley Brezenoff
(served on CTRDAC 5/94 to 1/95)
Executive Director
Port Authority of New York and New Jersey

Dr. Janet Welsh Brown
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Metropolitan Transportation Commission
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Mary Rose Loney
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Director of Aviation
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Brigadier General Robert Magnus
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Technical Advisor
NYMA, Inc.

The CTRDAC was divided into four major subcommittees: Aircraft, Safety/Environmental, Infrastructure, and Economics. The membership of each committee and its charter are shown below.

Subcommittee	Membership	Charter (Work Distribution)
Aircraft	**Hans Mark (Chair)** Wolfgang H. Demisch Robert Baker Morris E. Flater Denton Roy Hanford Barry L. Valentine Wesley Harris Brig. Gen. Robert Magnus, U.S.M.C. Henry Duffy Webb F. Joiner Gina Thomas Matthew Zuccaro	• Estimated costs of development, production, and operation of tiltrotor aircraft. • Performance characteristics, including flight envelope, environment, and safety. • R&D requirements. • Estimates of cost and time to develop a civil tiltrotor aircraft.
Environmental and Safety	**John H. Enders (Co-Chair)** **Dorn C. McGrath (Co-Chair)** Barry L. Valentine Matthew Zuccaro Janet Brown Henry Duffy Morris Flater Denton Roy Hanford Wesley L. Harris E. J. Hewitt	• Estimated noise and emissions characteristics of tiltrotor operations at and near vertiports and tiltrotor terminals. Review en route noise characteristics. • Estimated safety characteristics of civil tiltrotor operations. • Land use and siting implications given the noise and safety characteristics. • R&D requirements.
Infrastructure	**Susan J. Kurland (Chair)** Barry L. Valentine Stanley Brezenoff Lawrence Dahms Joseph Del Balzo Morris Flater Anna Sol Gutierrez George P. Howard Dorn C. McGrath Matthew Zuccaro	**Air:** • Procedures, including effects on safety and environment. • R&D requirements. • Effects on air traffic congestion (en route and terminal). • Costs of developing infrastructure and recommend how these should be shared by Federal, State, and local government and private industry • Regulations. • Facility design/costs. **Ground:** • Siting considerations, including safety and environmental concerns. • Zoning and local ordinances. • Financing.
Economics	**Mary Rose Loney (Chair)** Robert Baker Helane Becker-Roukas Joseph Del Balzo Wolfgang H. Demisch Morris Flater José Gómez-Ibañez Webb F. Joiner Michael Murray Gina Thomas Barry L. Valentine Todd A. Weiler Matthew Zuccaro	• Economic viability of civil tiltrotor service. Estimate the costs (capital and operating) of tiltrotor service in a range of potential markets. Estimate the extent for markets where tiltrotor service would be profitable. • Estimates of delay reduction. • Public assistance requirements for development of aircraft/infrastructure. • Comparison of pubic benefits and costs. • Impact on other air and surface modes, including connections to other modes of transportation. • Net employment effects. • Market potential for aircraft—national/international. • International competition. • How development cost should be shared between the Federal Government and the private sector.

In response to this direction, the CTRDAC has prepared a two-volume report to Congress.

Volume 1, the CTRDAC Final Report, summarizes the work of the four individual subcommittees and integrates their findings. It also contains an Executive Summary and summary chapters on CTRDAC findings and recommendations.

Volume 2, the CTRDAC Technical Supplement, contains five sections containing the five individual reports prepared by the subcommittees: Aircraft, Safety, Environmental, Infrastructure, and Economics. There are differences of viewpoint that will be apparent to the reader in these reports. This is to be

expected since the members of the subcommittees approached the subject from different perspectives. Some readers may find these differences of interest. By presenting the Subcommittee reports in this manner, readers will gain a better understanding of all the issues involved. Volume 1, the CTRDAC Final Report, represents the consensus opinion of all the members of the CTRDAC and the members fully endorse the recommendations of the report.

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Civil Tiltrotor Development Advisory Committee

Report of the Aircraft Subcommittee

CTRDAC Aircraft Subcommittee

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CTRDAC Aircraft Subcommittee Report

CTRDAC Aircraft Subcommittee Report

A1.0 Introduction

Tiltrotor technology is currently being developed for the military services through the U.S. Marine Corps V-22 Osprey. The tiltrotor provides a vertical take-off and landing (VTOL) capability with efficient cruise flight, through a combination of the best features of helicopters and turboprop airplanes. Though various VTOL concepts have been explored for decades, the core aircraft technologies of lightweight structures, digital flight controls, and advanced turboshaft engines have recently made the tiltrotor a reality. The introduction of a tiltrotor into the civil world could be the foundation for revolutionizing short-haul commercial aviation.

There are several commercial air transportation markets that could benefit from the introduction of various sizes of civil tiltrotors (CTR). This report focuses on the current state-of-the-art and the research and development needed for a 40-passenger vehicle. This aircraft has the potential to influence the high-density, short-haul commuter air market.

A1.1 Some History

The history of aviation has many examples of technology transfer between the military and the civilian sector. Air-cooled radial aircraft engines, all metal airplanes, and many of the guidance and control systems being used today were technologies first developed for the military and then, when economically viable, used on civilian aircraft. Perhaps the most important example is the introduction of jet-propelled bombers, the B-47 and the B-52. These aircraft were designed to carry nuclear weapons and were the backbone of our strategic deterrent force for half a century. Large jet-propelled aircraft technology was gained from flight experience with these two aircraft. Initially, two important technical problems had to be solved. The first was to produce safe and efficient turbojet engines that had lower maintenance costs and better safety records than conventional piston engines. The second was to understand the properties of large flexible airplane structures where the wings had to be built to bend much more than those on smaller conventional piston engine powered aircraft. This, in turn, required a new and better understanding of the fatigue properties of structural materials.

These lessons were absorbed and implemented in the early tankers and transport jet aircraft. For example, the KC-135 program was stimulated by development of the model 367-80 prototype. The U.S. Air Force subsequently bought the KC-135, which was followed by the decision to develop and introduce the 707. In this case, there was direct technology transfer between a military aircraft and the civilian efforts.

The V-22 tiltrotor transport is currently being tested by the U.S. Marine Corps. Based on the current delivery schedule, the V-22 will have met its maturity goal for reliability of 60,000 flight hours by 2005. Inevitably, tiltrotor development knowledge will benefit from the experience gained from both the flight research aircraft XV-15, as well as the two phases of the V-22 development, the full-scale development (FSD) and engineering and manufacturing development (EMD).

By flying these relatively large tiltrotor transports for some years, the military will provide the necessary experience to judge whether an aircraft

such as the V-22 tiltrotor has the potential for profitable applications in the civilian sector. Although the experience of the KC-135 and the 367-80 is instructive, there is a general consensus that the unique military capabilities built into the V-22 make it an unlikely candidate to be developed as a direct civil counterpart. And, it is very likely that V-22 technology will be applied to an aircraft configuration specifically adapted to civil market requirements. Therefore, it becomes extremely important to closely examine our military experience with the V-22 to gain a better overall understanding, as well as the specifics, of tiltrotor technology.

A1.2 The Fight Experience of the Military V-22 Osprey Aircraft

What will be learned from the V-22? Most likely, many of the same things learned from the large jet-propelled airplanes. First and foremost are the predicted operational costs. Although military aircraft operate in different environments, they will provide an operating cost "baseline". Additionally, they will illustrate failure modes of a relatively complex configuration such as the V-22. Careful examination of an aircraft structure that has been flying for many hours always reveals unanticipated faults. Ultimately, correcting these faults leads to a safer airplane. The V-22 will also provide information on aircraft maintenance issues and costs, elapsed times, and frequency of required maintenance. This will provide an understanding for the required spare parts inventory and the training levels required for maintenance personnel.

Other lessons to be learned include: (1) evolution of tiltrotor flying qualities and aerodynamic performance technologies, (2) development of flight control gains and phasing versus flight mode, (3) understanding of external environment, including rotor downwash/outwash and exhaust temperature considerations, (4) operational and piloting techniques, including takeoffs and landings, use of nacelle tilt, use of rotor revolutions per minute (rpm) and flaps, ground handling, and (5) understanding of tiltrotor aerodynamic interactions.

A point to be considered is the development of an experimental flight program. The proposed research program will require flight experience. This will answer some open questions that must be answered before a CTR can be seriously considered. This proposed flight program can be carried out with a suitably modified V-22 that will be designed based on analytic and test results from the National Aeronautics and Space Administration (NASA) Short-Haul Civil Tiltrotor research and development study.

In addition to a flight research program carried out with a modified V-22 aircraft, it may be necessary to produce a prototype of a commercial CTR aircraft as part of the development and production effort. This would serve as the certification vehicle after a successful program launch. Such a vehicle would also be of value in determining passenger acceptance.

The major U.S. helicopter manufacturers are working in cooperation with NASA through the Short-Haul Civil Tiltrotor research and development effort. As part of this program, NASA has already developed a baseline configuration for a CTR aircraft using 1994 technology to help in assessing the value of the various ongoing technology studies. In addition, manufacturers have developed a configuration called the CTR2000 using expected "year 2000" technology. While a flight research program is absolutely necessary for the creation of a CTR aircraft, there is also necessary research and development to be conducted focused on a production vehicle.

A2.0 Operational Issues

The V-22 will provide the basic, or core, tiltrotor technologies, including handling qualities, performance, dynamics, and stability. However, it is important to develop a list of things that will not be learned from military V-22 flight experience. For the civil tiltrotor (CTR), the key additional technologies that must be developed are those that are unique to commercial operations. These include commercial levels of safety, low external noise and emission levels for community acceptance, low internal noise and vibration for passenger comfort, and competitive economics, including low acquisition cost, operating costs, supporting costs, and good availability. These operational needs can be directly related to the key technologies that must be developed or matured in the next 5 to 7 years.

• *Can a CTR aircraft be developed that is safe and certifiable by the Federal Aviation Administration?*

The answer to this question is 'yes'. However, the development of a strong research program to look at safety and eventual certification must be given the highest priority. The failure modes of the tiltrotor aircraft configuration will have to be thoroughly understood. Engine-out behavior and recovery following total power loss must be examined in accordance with Federal Aviation Regulation (FAR) requirements.

Properly redundant flight control systems must be developed and tested to ensure that they can eventually be certified. The same is true of the structural materials from which the aircraft would be built. Reliable engines, rotor systems, transmissions, and drive trains must be available. Before the Federal Aviation Administration (FAA) grants certification, all of the failure modes of the aircraft will have to be thoroughly understood and resolved. With 40 years of experience flying tiltrotor aircraft, such as the XV-3 in the 1950s and 1960s, the XV-15 in the 1970s and 1980s, and the V-22, it is likely that these issues can be properly considered during the certification process.

• *Can a CTR aircraft be developed that is environmentally acceptable to the communities in which it must operate?*

There are two major issues that need to be dealt with to answer questions about environmental acceptability. The most important of these is to design a CTR for inherent low noise and to operate a CTR aircraft in such a way as to minimize the noise signatures to which the communities will be exposed. The design of a quiet rotor system and the development of noise abatement operating procedures will require an extensive research program. A second objective is to minimize exhaust emissions. This problem is less important than noise today but may become significant in certain communities sometime in the future.

It is clear from the technical issues that have been outlined that a flight research program will be necessary to answer these questions. The Civil Tiltrotor Advisory Committee (CTRDAC) Aircraft Subcommittee makes some recommendations regarding such a program in this section of this technical supplement.

• *Can a CTR aircraft be developed that is acceptable to passengers and that can be profitably operated by commercial airlines?*

Passenger acceptability is one of the keys to eventual profitable operation of CTR aircraft. In contrast to the military version, civilian passengers will have other ways of traveling if they do not like the tiltrotor. Internal noise levels will have to be at least as low as conventional civil transports. Vibration levels must also be acceptable. Research and

testing will be required to ultimately produce a CTR that successfully meets the market requirements of passengers.

Another element of passenger acceptability has to do with the flexibility of scheduling made possible with a CTR. Whether this advantage can be fully exploited depends on the infrastructure that will eventually be developed to accommodate CTR operations. Currently this infrastructure development is an open question that will have to be determined by the transportation market.

In examining markets, it is important to keep in mind that the tiltrotor aircraft has the potential of developing new markets as well as serving those that already exist. To illustrate this point, there is the following (definitely apocryphal) story. Before Henry Ford committed to mass production of the Model T, he asked a market analyst to perform a study. The analyst produced the usual glossy and leather-covered report that stated that mass producing automobiles was not a good idea. He reasoned that there were not enough roads in the country for their use. The idea that the existence of a large number of automobiles would drive the construction of more roads never occurred to the analyst!

A3.0 Description of Proposed Research Program

The following sections discuss the research and development (R&D) program necessary to answer the questions that will not be addressed by operating the V-22 in the military sector. There is also a discussion of the funding of such a program and sharpening of the list of capabilities that a CTR transport should have. It is these capabilities that will ultimately determine what market such an aircraft could serve.

The research program proposed is oriented towards answering the operational questions raised by the safety, economic, and infrastructure requirements of a civil tiltrotor (CTR) air transportation system. This is illustrated in the matrix chart shown in figure A3.0-1. The vertical column on the left side shows the critical technical elements for which research is required. The important operational issues are listed across the top of the chart. The marks in the matrix illustrate to which operational problem the research is most relevant.

A3.1 Flight Controls (Safety and Certification Question)

The V-22 currently uses a triply redundant, fly-by-wire (FBW) flight control system that operates without a mechanical backup system. Current Federal Aviation Administration (FAA) practice is to certify FBW systems with a rudimentary mechanical backup. The FAA requires a level of flight control system reliability such that any flight critical failure is "extremely improbable". Although not explicitly stated, this is generally interpreted as less than one occurrence in 10^9 flight hours. By comparison, the military qualification requirement for the V-22 is for less than one occurrence in 10^7 hours. Thus, commercial certification requires a flight-critical reliability that is two orders of magnitude higher than the military requirement.

The FAA recently certificated the A330 and A340 aircraft that are equipped with a FBW flight control system. The A330/340 system and the 777 system, which have both been certificated, have only rudimentary mechanical backup links capable of maintaining trim and providing limited control inputs but not full flight-control authority. The A330/340 system provides mechanical links to the rudder and horizontal stabilizer, while the 777 has links to one spoiler pair and the horizontal stabilizer. Thus, the FBW system is flight critical for these aircraft.

Critical Operational Issue	Safety & Certification	Community & Infrastructure	Passenger Acceptance & Economy
Advanced proprotor	X	X	X
Ultra-reliable dynamic system	X		X
Vehicle management system	X		X
Engine technology	X	X	X
Producible airframe	X		X
Design integration	X	X	X

Figure A3.0-1 Research and Development Technical Elements Must Be Focused on Critical Operational Issues

For the V-22, each of the three flight control channels is equipped with a flight control computer incorporating two data paths that are powered from three separate electrical sources. The V-22 also has three independent hydraulic systems. The architecture on the 777 is similar, although it uses a triplicate data path rather than the V-22 dual path. The additional redundancy has been incorporated to assure dispatch reliability. It is likely that the CTR system would be configured in the same way. In that respect, assuming successful experience with the A330/340 and the 777, the FBW architecture/control media used on the CTR will probably be certifiable.

An alternative solution to FBW technology is the development and use of a fly-by-light (FBL) flight control system. This technology, while still under development, has impressive possibilities. However, for FBL control systems, many of the reliability issues of an FBW are still present with the addition of FBW-to-FBL conversion hardware added for computer and actuator interfaces. An FBL system uses fiber optics to transmit signals from the cockpit to the control surfaces and the engines. Such a control system would effectively eliminate the problems associated with lightning, electromagnetic interference, and high-intensity radiation fields. While fiber optic data links may be incorporated in the flight control system, the optical transducer technology is not yet sufficiently mature to support application to a first-generation CTR. A major research effort would be required to make the FBL technology a viable system.

The use of a dissimilar FBW system to back up a redundant digital system might also be a promising approach. At present, the FAA has responded positively to the idea of a dissimilar backup system for use in a CTR aircraft. Such a system would accomplish the same tasks as the A330 and A340 flight control systems, although a different software program would be used for the redundant system.

Should neither FBW nor FBL technology be able to achieve FAA certification, requirements may mandate the use of a rudimentary mechanical backup system. The XV-15 demonstration flights in the 1970s and 1980s used a mechanical flight control system. However, this system proved to be bulky, heavy, and sluggish. It is believed that incorporation of the XV-15 system into a CTR would be possible but difficult. Furthermore, an undesirable weight penalty associated with the system would also be incurred with this incorporation. For these reasons, if a rudimentary mechanical backup system is required for the CTR, the XV-15 mechanical flight control system should be analyzed and used as a baseline reference system from which a more capable, lighter weight, and easier-to-use system could be designed. Independent of backup options, the primary objective should be to produce a CTR primary control system that is as safe and reliable as possible.

Finally, it should be noted that a challenge facing the certification of the CTR is in the redundancy of the hydromechanical tilt and swashplate controls, not the control methods. R&D programs should be conducted to increase the reliability of flight critical control actuation.

A3.2 Failure Modes and Safety (Certification Question)

A3.2.1 One Engine Inoperative

The ability to operate the CTR with one-engine-inoperative (OEI) is imperative for FAA certification. The V-22 has OEI contingency capabilities. However, because the V-22 is a military aircraft, it is not required to meet the stringent FAA certification rules for commercial use. Any prospective CTR aircraft must be capable of meeting all Category A standards and performance requirements.

The OEI capability of the V-22 is centered around its transmission system. The transmission in each nacelle is connected to the other engine by a drive shaft that runs the length of the wings. This arrangement is called cross-shafting. The interconnect shaft provides a fundamental element of flight control coordination in addition to safety, since the interconnection permits hovering roll or

pitch control to be provided from differential rotor thrust without incurring lag times required to change engine power levels. When one engine fails with this design, the other engine can drive both rotor systems, allowing the tiltrotor to continue to fly and land safely. It should be noted that both the XV-15 and V-22 aircraft have actually put this capability to the test. Reports from these incidents illustrate the success of this OEI system. During V-22 training, OEI flights are routinely practiced in the airplane mode. Any prospective CTR should use an OEI contingency design similar to the XV-15 and V-22.

A number of issues need to be addressed in designing for OEI incidents. Perhaps the major issue associated with OEI performance is providing sufficient contingency power levels from the engines and through the transmission without penalizing fuel consumption for routine flight operations or significantly adding empty weight. A second issue is providing technology for power assurance based on diagnostic systems rather than actual emergency power checks at emergency power levels. The third issue is reducing the pilot workload under emergency conditions by optimizing the flight deck and cockpit management system to enhance displays and to incorporate some level of automation.

Knowledge and understanding of these areas must be complete before operational procedures for an OEI situation can take form. Furthermore, research must be carried out to ensure that an OEI landing can be successfully completed while fulfilling all Category A standards and performance requirements.

In November 1994, extensive OEI simulations were conducted, using the Vertical Motion Simulator (VMS) at the National Aeronautics and Space Administration (NASA)-Ames Research Center. The major focus of these tests was to further the understanding of how the V-22 and its pilots react in an OEI contingency situation in the terminal area. Experiment results support the notion that safe takeoff and landing operations can be conducted with a CTR into small vertiports when the single engine installed contingency engine power level is near the hover power required. While simulations have an important place in the research program, a flight test program will also be necessary. Initially, the V-22 and possibly the XV-15 can be used for this purpose. Ultimately, it may be necessary to build a CTR prototype in order to conduct a truly definitive flight research program.

A3.2.2 Flight Critical Failures

The existing Federal Aviation Regulation (FAR), Part 29, "Airworthiness Standards: Transport Category Rotorcraft," requires that "it must be possible to make a safe landing on a prepared landing surface after complete power failure occurring during normal cruise." The proposed new FAR Part XX, "Interim Airworthiness Criteria: Powered-Lift Transport Aircraft," similarly states that, "In all en-route flight phases and corresponding aircraft states, it shall be possible to maintain control following loss of power from all engines and to change the aircraft state/configuration as necessary for an emergency landing". Should the tiltrotor experience a total power failure during an en-route flight phase, it would normally recover by making an unpowered gliding descent to an emergency landing at a nearby airport, in a manner similar to a conventional civil transport.

The Interim Airworthiness Criteria also recommends that "In areas of design where the specifics of powered-lift concepts are sufficiently similar to airplane or rotorcraft standards, it is believed that it would be appropriate to continue to use established standards which are the result of aerospace industry and FAA experience." Since tiltrotors will be operating in a manner similar to helicopters in at least the takeoff and landing phases of flight, transport category helicopter FAR 29 standards for control in the event of total power loss should be examined as well. FAR 29 imposes the additional requirement on transport category rotorcraft of demonstrated control in the autorotation over a wide range of flight airspeeds from 0.5 times the maximum range glide speed to the appropriate never-exceed speed. It is currently under debate

how this specific requirement will be applied to tiltrotor aircraft, but it is recognized that CTRs must be at least as safe as today's rotorcraft. It should be noted that modern engine technology makes the probability of dual engine failure extremely remote, which has led to the successful introduction of Extended Twin-Engine Over Water Operations (ETOPS) for commercial jet transports.

In addition to engine failure, the tiltrotor is subject to potential flight-critical failures of other dynamic components within the power train, including elements of the rotor and drive system. Whereas contemporary engines experience a single engine in-flight shutdown rate of the order 10^{-5} to 10^{-6}, other dynamic components have flight-critical failure rates of approximately 10^{-6}. Research is strongly recommended to support a major improvement in these failure rates, to increase dynamic system safety to a level compatible with that of the flight control system. The areas of highest payoff include: (1) systems condition and usage monitoring, often called health and usage monitoring systems (HUMS), (2) improvements in gears, bearings, and material technology, and (3) increased emphasis on fault-tolerant designs.

A3.2.3 Tiltrotor Conversion Mechanism Failure

Obtaining FAA certification for a CTR will depend on many things, among them the capability of a CTR to overcome a helicopter-airplane conversion system failure and land safely. A critical conversion failure is defined as a situation in which one or both of the nacelles cannot be rotated from their horizontal (airplane) configuration to their vertical (helicopter) configuration. The major problem associated with a conversion failure on a V-22 type tiltrotor is that the rotor blades on the V-22 are 19 feet long (rotor radius) while the centerline hub-to-ground clearance of the nacelle in an airplane mode is only 12.3 feet. Obviously, the V-22 is incapable of landing undamaged when the engine nacelles are in the airplane mode position.

To prevent a total failure of the conversion system on the V-22, a triply redundant Hydraulic Screw Drive System (HSDS) is used. Under nominal operations, the V-22 uses both of the hydraulic screw drives located at the ends of its wings. Should one or both of these hydraulic systems fail, the full-scale development (FSD) V-22 has an electrical conversion system located at the end of each of the screw drives to power the nacelles when a conversion is required.

In the unlikely event that a total failure of the conversion system does occur, landing the vehicle in airplane mode becomes the only alternative. Because the rotor blades are made of composite materials, these blades will literally splinter into pieces when they strike the ground during an airplane-mode landing, thereby causing only minimal damage to the vehicle and its cargo. A related event actually occurred when the V-22 aircraft rolled close to the ground in the helicopter mode. The rotor blades behaved essentially as described above.

For this reason, it is believed that a failure in the conversion system of the CTR aircraft can be reduced to a simple redundancy problem. Therefore, if the redundant system fails, the vehicle can still land in airplane mode with minimal damage. Every effort will have to be made to incorporate a fail-safe and automatic conversion system into CTR. It is important to note that even minor conversion system malfunctions in the XV-15 and the V-22 have been extremely rare in all of their combined flight experience to date. The conversion system designs have proven to be exceptionally reliable.

Should a triply redundant conversion system, similar to the one currently employed in the V-22, prove inadequate for certification purposes, variable-size rotor blades may be an option. Variable-size rotor blades have been researched for some time now as a means of solving some problems associated with a CTR aircraft. When the tiltrotor is in helicopter mode, the rotor blades would be extended to their full length in order to provide

maximum lift for the vehicle. In airplane mode, the rotor blades would be retracted back to a given dimension that would optimize engine and flight performance. With such a system, it would be possible to land the CTR in the airplane configuration without damaging the vehicle. However, a significant research program is necessary to determine the reliable operation of variable rotors before these can be properly incorporated into the CTR aircraft.

A3.3 Icing (Certification Question)

Critical to the operation of a CTR aircraft is all-weather capability. If a CTR aircraft is not capable of operating under adverse weather conditions, then its usefulness will be severely limited. The V-22 aircraft will be qualified to operate in "moderate" icing conditions for the military and should, therefore, serve as a basis for implementing a CTR icing capability. This moderate icing rating will allow the tiltrotor to operate in icing environments that meet or exceed safe operating limits for all helicopters presently in military service.

On the V-22, a conventional pneumatic boot on the wings and an electrothermal system can be used to handle icing conditions. The deice pneumatic boot can be inflated and then deflated again when ice forms on the leading edge of the wings of the aircraft to break up any ice that has formed. The anti-ice electrothermal system consists of electrically heated elements embedded within the proprotors, canopy, engine inlets, and windshields. These elements can be operated whenever icing conditions occur, thereby preventing accumulation or removing ice from critical components of the aircraft.

The effects of using deicing fluids on the composite materials of the aircraft itself will have to be considered and evaluated to determine if they exhibit any corrosive behavior. The use of Type 2 deicing fluids at major airports is expected to become commonplace by the turn of the century. However, due to the environmental concerns associated with covering aircraft wings with these fluids, questions arise as to whether the FAA or the Environmental Protection Agency (EPA) would permit these fluids to be used on tiltrotor aircraft at vertiports in local communities. If the use of such fluids is not allowed in local communities, alternative deicing fluids and methods will have to be researched to ensure that a tiltrotor can operate in icy weather environments.

A suggested area of research is the physics of rotor blade ice shedding and the impact of the ice on the airframe. The V-22 approach to this problem is to continuously heat the blade leading edge to ensure that shed ice is relatively small. However, flight testing could quantify these effects and the test results could be extrapolated to other flight envelope conditions through the use of analytical development.

A3.4 Composite Materials, Structures, and Manufacturing (Certification Question and Economic Issue)

A3.4.1 Composite Materials

A significant advanced technology being incorporated into the V-22 aircraft is composite materials. A large percentage of the composites incorporated into its design are carbon (graphite) fiber epoxy laminates. The use of this composite material has many benefits. The weight of the vehicle is greatly reduced without compromising its stiffness. In addition, the vehicle has the ability to function in certain corrosive environments that affect conventional metal structures without sustaining damage. Furthermore, the manufacturing process is more efficient due to the ability to produce complex shapes. For this reason, the costs of manufacturing the vehicle are also reduced.

An additional advantage of composite materials is the ability to tailor the properties of a structure, in terms of mass, stiffness, and strength, both by combining different composite materials in one structure and through the details of the ply-by-ply lay-up used in the construction. By tailoring the structure, it is possible to optimize the elastic response of the structure to the aerodynamic loads. This feature is particularly important to tiltrotor

structures, providing an additional approach to satisfying aeroelastic and vibration requirements. Advanced design and manufacturing, as discussed in the manufacturing section of this report, such as fiber tow placement, improve the ability to fabricate tailored structures. Research should be conducted in this area in order to support the unique needs for development of tiltrotor structures technology.

Recently, the FAA certificated the Starship, the first all-composite aircraft, for "general aviation" (Part 135) but not "commercial" (Part 121) use. This airplane uses a "sandwich"-type composite fuselage design. Graphite composite sheets are bonded together with a honeycomb Nomex core sandwiched in the middle. The use of this approach is projected to result in a less expensive airframe than would be obtained from using the V-22 aircraft graphite-epoxy laminate structure. The V-22 design currently does not incorporate the Nomex honeycomb construction. Manufacturers have used a composite sheet material for the CTR design.

In the design phase of the V-22, the Navy would not approve such a construction for the primary structure, citing experience with problems of water ingestion on honeycomb panels. However, recent advances in material technology have lead to the development of a thermoplastic interleaf film that can be used as a moisture barrier for honeycomb construction. Specifically, a polyether-ether-ketone (PEEK) thermoplastic film/epoxy adhesive interleaf has been developed to eliminate face sheet permeability in co-cured sandwich structure. In addition, new core materials such as DuPont Korex and Hexcel thermoplastic core (TPC) have been developed to reduce or eliminate intercellular moisture migration in the event of skin punctures. These developments also promise to be valuable in eliminating potential leak paths in pressurized composite structures. A full-scale composite structure of this type should be developed to fully validate the advantages of this method of construction.

The primary issues concerning the use of composite material structures are quality control, extended fatigue life, and failure modes of the composite materials and structures themselves. Various failure criteria theories are currently used in the industry. The differences among the lifetimes predicted by these different failure theories has generated widespread concern. In order to ensure Government certification of a CTR , this concern must be dealt with accordingly. For this reason, it will be necessary to establish a unique failure theory with which to predict the mean times of failure in laminated composite structures accurately. Much work of this kind is already going on in connection with the use of composites on conventional aircraft. Therefore, this point should be taken into account when the CTR-unique R&D budgets are presented.

Although the use of composite materials for primary load-bearing structures could yield promising results in the commercial aircraft industry, it is important to note the primary barriers to their acceptance. The areas of quality control in the manufacturing process and fatigue failure predictions in the line inspections are important issues that must be researched and regulated so that Government certification may be obtained for aircraft using composites. Because of their anisotropic, laminated nature, composite materials have a more complicated response to loading and more complex failure modes than do isotropic materials. Additionally, the susceptibility of composite structures to elevated temperatures and moisture must be considered.

Regardless of these barriers, one manufacturer has successfully manufactured all its rotor blades from composite material since 1976. Overall the company has produced approximately 9,000 blades of extremely high quality. A similar statement can be made about other helicopter manufacturers. A combination of ultrasonic and X-ray inspections are made of all final blades. Any minor anomalies can be corrected by injecting a room-temperature curing resin into small voids. Currently, all blades are on-condition maintenance (no scheduled removals), and there has never been a flight-critical failure of a composite blade. These blades have

been certificated by the FAA for use on a commercial helicopter. In the case of a second manufacturer, FAA-certificated rotor blades are used on several helicopter models manufactured by the company.

Composite primary structures, such as rotor blades, are damage tolerant. Typical failure modes involve delamination between plies of the composite materials with a subsequent softening of the structure. In areas where dynamic response is important, the local softening is immediately apparent as a change in vibration. These failures are also normally visible to the eye. In view of these characteristics of composite construction, together with an extreme degree of structural redundancy in airframe structures, structural design should be based on damage tolerant concepts with replacement on-condition.

A barrier to realizing the full potential of composites has been the incomplete knowledge of their structural properties, including the environmental effects and damage propagation. As a result, composite structures have been conservatively designed, accepting heavier-than-desirable structure in many cases. It is anticipated that more realistic reduction factors due to environmental effects will be developed as the use of new tougher resin systems becomes more widespread and as experience is gained with the use of such parts in service.

A comprehensive research program into composite materials is currently underway in the NASA Advanced Composite Technology (ACT) and Composite Element of the Advanced Subsonic Technology (AST) programs. The findings of these research projects should provide a wealth of data concerning composite materials and their possible applications. Every effort should be made to incorporate this basic materials knowledge into the CTR while additional tiltrotor-unique R&D is conducted. Most of this work will be done in the laboratory, but it is possible that eventually some flight experience may be necessary. For most purposes, an aircraft designated for material research should suffice.

A3.4.2 Manufacturing

The introduction of high-speed computers has completely changed manufacturing in aircraft as well as in other industries. For this reason, companies must now concentrate on designing and building aircraft using automated digital methods in order to reduce costs, change-overs, redesigns, and manufacturing time. The early use of composites was based on design and manufacturing approaches developed for metal structures. These relatively inefficient practices, coupled with the high cost of limited qualities of materials being produced, caused the applications of such materials to develop very slowly. This area represents a major research opportunity in order to reduce costs, speed productivity, and ensure a high level of quality control on production and fabrication of the aircraft and its component parts.

Enormous strides are now being made in the application of digital technology to the design and manufacturing process. Digital product definition, through such design systems as Computer-Aided Three-Dimensional Interactive Application (CATIA), is being linked directly into manufacturing, from the design and development of the tooling to the actual fabrication of major metal and composite components and structural elements. Automation is further improving productivity. One of the major new manufacturing technologies now emerging is the fiber tow placement, in which a fiber bundle, or tow, is placed by a moving head directly onto a rotating mandrel to develop a large structure in one continuous operation with minimal manual labor. The entire structural development process, from design to fabrication to nondestructive evaluation, is controlled by a digital sole authority data set.

A composite structures R&D program should be implemented to develop a full-scale fuselage and a full-scale wing, using fiber tow placement and the other advanced design and manufacturing technologies. These structures should have elastic and strength properties that are optimized for the unique needs of a CTR.

Research must be conducted to implement a high level of quality control throughout the production process. Of particular importance is the assurance of quality control during the fabrication of the composite components of the CTR aircraft. There is no doubt that people placed in the appropriate sensitive positions in the manufacturing process will continue to be vitally necessary. However, it remains to be determined exactly what role people will play in the production of CTR aircraft.

Research into the manufacture of as many as 500 CTR aircraft requires a major thrust. The advantages gained using digital-design techniques and cross-functional design-build teams should be examined. However, research into automating the manufacturing process itself, through the use of computers and high-speed tooling machines, should be the major thrust of this research effort. Further attention should also be given to the questions of quality assurance of the composite materials being used on the CTR aircraft.

If the number of CTR aircraft to be produced is too small, then investing in a fully automated plant becomes economically undesirable. Therefore, early information on the size of the anticipated production run will be critical to any plant automation decisions.

A wealth of knowledge will be gained by examining how the V-22 production experience progresses. Particular attention must be paid to the advantages and disadvantages of the V-22 production system while still looking into areas where improvements can be made when a CTR production line begins. We must also take advantage of the experience gained from manufacturing the V-22 so that the learning curve of the CTR aircraft will reach the asymptotic unit cost sooner than the V-22 (figure A3.4.2-1).

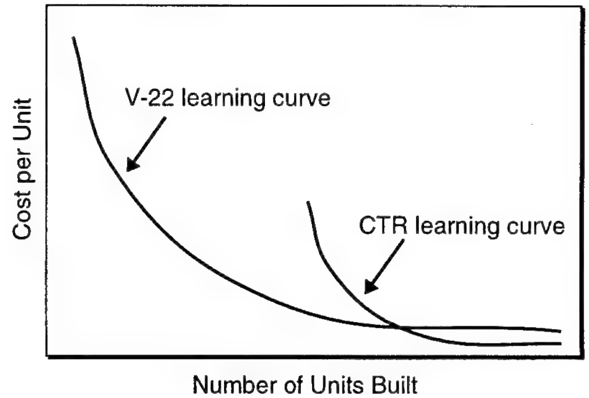


Figure A3.4.2-1 Vehicle Production Learning Curves

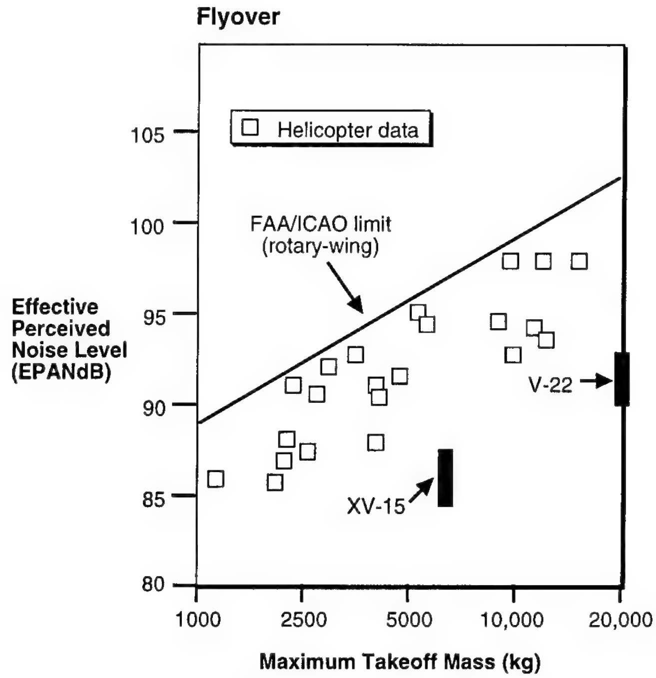
A3.5 Noise (Acceptability Question)

A3.5.1 External Noise

External noise reduction is a major issue to CTR aircraft acceptance and operation. The predicted noise levels of the V-22 that would be experienced if it were operating in a commercial vertiport environment are presented in figure A3.5.1-1. This figure compares V-22 and XV-15 noise levels with helicopter and fixed-wing noise certification levels. The figure shows that the V-22 is on the borderline of meeting the FAA/International Civil Aviation Organization (ICAO) requirements for approach, although it would easily meet the requirements for flyover. This figure also shows the comparable fixed-wing requirement for the approach condition. One should note that the fixed-wing measurements are made at 450 meters from the source, rather than 150 meters as required by helicopters or tiltrotor aircraft.

As indicated above, the V-22 could meet existing FAA regulations. However, due to the nature of the CTR aircraft and the possibility of operating it in high population areas, it is crucial to reduce noise levels as much as possible. Continued research defining a community acceptance guideline is recommended. While Federal noise certification and regulations are important to understand, a concentrated effort must be undertaken to ascertain the community noise pollution standards that are in place around the country that would affect the operation of the CTR aircraft in local communities. It is not possible for the Federal Government to impose standards that supersede locally imposed levels of acceptability. This is stated in FAR Part 36, page 1: "Compliance with Part 36 is not to be

- Certification noise level requirements are similar but sideline microphones are one-third the distance from the centerline
- In the airplane mode, tiltrotors are much quieter than helicopters
- In the VTOL mode, tiltrotors tend to be noisier than helicopters (higher tip speeds, higher disk loads)



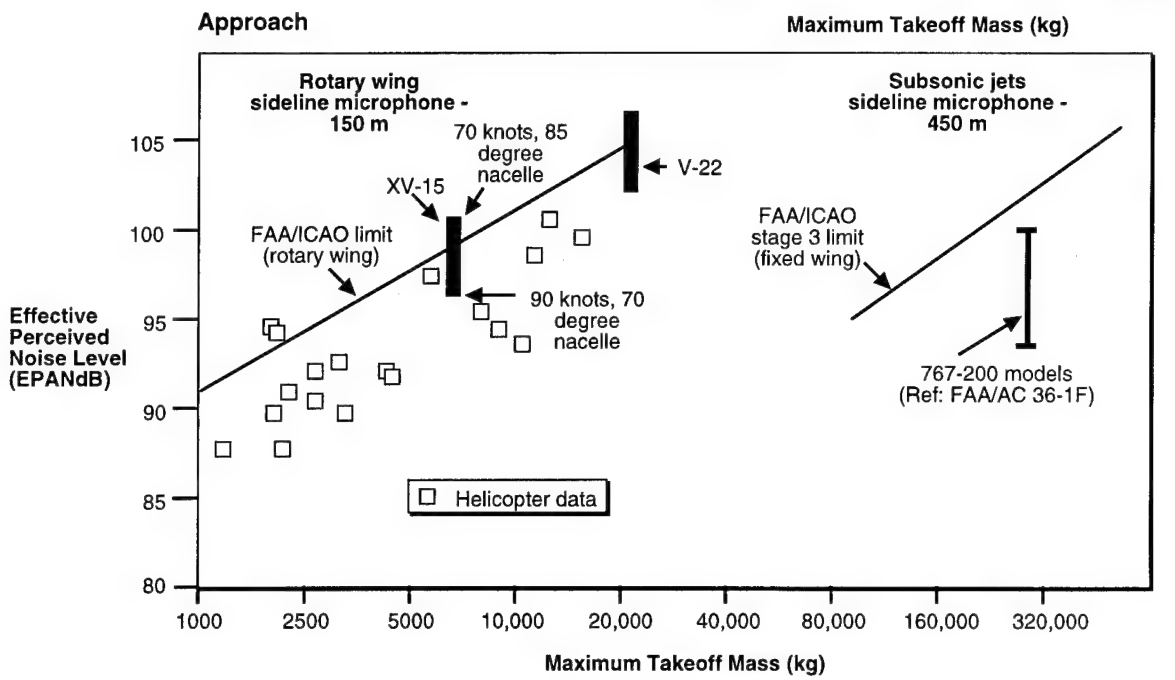


Figure A3.5.1-1 Rotary Wing Aircraft Have To Be As Quiet As Airplanes But At Closer Distances

construed as a Federal determination that the aircraft is acceptable from a noise standpoint in particular airport environments,—responsibility for determining the permissible noise levels of aircraft using an airport remains with the proprietor of that airport and surrounding community."

The established standard for Federally funded airports is provided by FAR 150. This standard, which can be superseded by community requirements as stated above, establishes a metric called Day-Night-Level (DNL) which is both a time- and frequency-weighted metric. These are 65 DNL for

residential, 70 DNL for business, and 75 DNL for industrial environments. While there is some question as to whether existing noise metrics properly account for the impact of low-frequency sound on human acceptability, the FAR 150 requirements must be viewed as the best standard that currently exists. It should be noted that the subjective noise evaluations now being made at NASA-Langley may eventually lead to adjustments of the metrics. Based on the FAR 150 and perhaps more stringent community standards, the V-22 noise levels should be reduced by approximately 10 to 12 dBA.

The current research and development programs at NASA have accepted the 12 dBA reduction as a goal with half being achieved through flight path management and half being achieved through source noise reduction. Flight path management should not adversely affect safety. Simple changes to nominal trim schedule may make substantial improvements in noise reduction during final approach and landing without compromising safety.

The overall purpose of flight path management is to reduce noise by airspeed and nacelle trim angle variations and the execution of flight trajectories that minimize sound levels on the ground while maintaining safety of flight for the aircraft. It should be stressed that there is still a lack of acoustical data for the V-22 aircraft. These data will be essential for any further development of flight path management for which consideration of initial descent altitude and its effect on aircraft safety must also be taken into account. Data from the XV-15 flight data base will be useful in that connection.

External noise from rotary-wing aircraft is at its highest level during approach to landing when the rotors experience Blade Vortex Interaction (BVI). BVI occurs when the high-speed vortex generated by a leading rotor blade is encountered by a trailing blade. Keeping rotor tip speeds down to a minimum would minimize the effects of BVI, thereby reducing external noise. The CTR rotor system should therefore be designed such that tip speed minimization is a major design factor. Regardless of the final design for the CTR aircraft, it is believed that overall external noise will not be reduced enough to satisfy the 10 to 12 dBA goal by simply reducing tip speeds. The influence of tip shape on noise is being pursued actively at both NASA-Langley and NASA-Ames.

While BVI is an important element of noise in final approach and landing, other important contributions are due to blade loading and blade thickness, both of which are particularly important at the very low frequencies which are objectionable to people. The contributions from these additional sources must be considered since the treatment of blade trailed vortex (noise) alone is insufficient to meet the overall noise reduction goal. All three of these elements (i.e., BVI, thickness, and loading) can be reduced by various means, including a reduction in rotor tip speed and increasing the number of blades. This is one of the proprotor subjects of the ongoing Short-Haul Civil Tiltrotor research program.

Active noise reduction is another solution to the problem that shows great promise for the future and has already yielded impressive results. One manufacturer, in conjunction with NASA-Langley Research Center, has devised an experimental method of placing computer-controlled flaps on the ends of rotor blades in an attempt to lessen BVI. Initial results of the study have already yielded a 4 dBA reduction in external noise under controlled conditions. A goal of reducing external noise levels by 12 dBA has been set. However, an operational system with Government certification remains at least 10 years away.

Even if this technology were in place to effectively reduce noise levels by 4 dBA, a major effort would be needed to adapt this capability to the CTR aircraft. Aeroelastic stability, dynamic loading, and vibratory and hub loading are just a few of the areas needing further research to successfully implement such a system. For this reason, it is judged that active external noise control will not yield benefits to the CTR project. However, this system should be taken into consideration when a second-generation tiltrotor is developed.

The reduction of external noise is likely to be the single most important objective of a CTR aircraft research program. This point has been recognized by NASA and industry and they are currently conducting an extensive program to solve the external noise problem. A V-22 demonstrator with a new, low-noise rotor system is recommended to substantiate the analyses and scale tests to be performed under Short-Haul Civil Tiltrotor Program.

A3.5.2 Internal Noise Reduction

Internal noise does not represent a certification problem. However, reducing internal noise is of the utmost importance for passenger comfort and acceptance. Since the V-22 aircraft was designed as a military transport vehicle to meet the requirements of MIL-STD-1294, only very minor considerations were made for internal noise levels.

The use of passive acoustic treatments on the CTR aircraft will aid in reducing internal noise. Applying such a treatment to the fuselage will dampen noise levels inside the aircraft. In addition, passive tuned-dampers may be used to further reduce noise levels. However, both cost and weight penalties will be incurred using these systems. Therefore, research should be conducted in these areas in order to minimize weight and cost while at the same time maximizing noise reduction.

Active sound reduction has been proposed as a potential solution to internal noise reduction. The active sound reduction systems are divided into acoustic systems, which use a canceling sound field from speakers to cancel airborne sound waves, and structural systems, which use structural excitation to cancel structure-borne sound waves. Active noise suppression systems have been in use for many years in a multitude of industries including both the automotive and aerospace sectors. Currently, electronics companies are marketing active sound control systems which can generate up to a 6 dB abatement. This would result in a 50 percent reduction in sound pressure inside the fuselage of aircraft.

The major hurdles for implementing an active noise system are developing small lightweight actuators, increasing controller speed, and improving the handling of multiple frequencies and source locations. It should be noted that the CTR generates very low frequency sound in the airplane mode and, given the size and power considerations, it is improbable that the acoustic system that uses a canceling sound field from speakers could adequately cancel out these low frequency sounds. However, it may be an effective complement to other approaches, and further research could be beneficial in developing an effective cancellation technology.

A3.6 Vibratory Loads (Safety, Certification, and Passenger Acceptability Issues)

A3.6.1 Vibratory Loads

An important objective in the design of a CTR is to provide the passengers with very low vibration levels, consistent with their expectation of a comfortable ride equivalent to their experience in jet airplanes, i.e., "the jet-smooth ride". In addition, the vibration levels throughout the entire airframe should be such that there will be no deterioration of aircraft components, including electronic, hydraulic, and/or mechanical items. In order to achieve these low levels, passive treatment may be used given it yields the minimum complexity and the least need for continuing maintenance.

The tiltrotor experiences vibration in helicopter flight mode due to nonuniform aerodynamic loading on the rotor, in a manner similar to conventional helicopters. In the airplane mode of flight, the tiltrotor experiences vibration since the rotor operates in the presence of wing/fuselage aerodynamic flows and the passage of the rotor blades through this velocity field induces harmonic vibratory responses at the blade passage frequency. A further excitation in cruise flight is due to the harmonic wake from each blade flowing back into the tail surfaces. An important approach to reducing vibration in all flight modes is to increase the

number of blades on the rotor. By doing this, the aerodynamic loading of each blade becomes proportionally smaller, reducing the effect of each blade in creating vibration, including both direct rotor contribution and the aerodynamic rotor-wing-tail interaction.

Even if the excitation is minimized, the blade response must be carefully controlled. In general, the most important thing is to dynamically tailor the natural frequencies of the blade away from the rotor rotational frequency. In a tiltrotor, this tailoring is more difficult given the high amount of blade twist and the large variation in blade pitch (collective) between hover and cruise modes of flight. However, in recent years, the technology of helicopter rotor dynamics has advanced to take advantage of the ability of composite materials to be tailored to provide an inherently low response of the blades at the fundamental rotor frequencies. This is an extremely high payoff area that has been proven for helicopters. Additional research is required to extend this technology to tiltrotors.

In addition to reducing the vibratory forces at the rotor, further attention must be paid to reducing transmission and/or amplification of the residual vibration through the airframe. This process is referred to as passive vibration attenuation. Finite element analyses, coupled to digital product definition, can predict vibratory responses accurately enough to guide the detailed structural designs while they are still "on paper". Final correlation with test data and adjustment of the structure is generally necessary to fine tune the structural response. Future research is needed to mature the optimization procedures for better natural frequency tuning or forced response minimization. The challenge of minimizing structural response is increased by the fact that conventional tiltrotors must vary the drive train revolutions per minute (RPM) by up to 18 percent to reduce tip speed in the cruise configuration. Thus, these aircraft will have to avoid natural modes over a range of excitation frequencies, rather than a single frequency.

Another method of achieving low vibration levels is active vibration treatment. Higher Harmonic Control (HHC), an active vibration treatment, was the subject of considerable research in the early 1980s. This research, which concentrated on applying higher harmonic control directly to the swashplate, demonstrated significant reductions in vibration and also made inroads in increasing the reliability of the actuators. Nevertheless, the studies also showed that the actuator power required and its impact on the hydraulic system requirements could lead to a major weight increase for the aircraft. An alternate approach that has been considered is to apply control individually to each blade. This could reduce the power requirements if applied through servo tabs or movable surfaces. However, either system adds complexity and potential reliability issues that could add significant risk and development cost. Despite its potential advantages, HHC is still in the R&D stage and is not ready for a first generation tiltrotor. Active vibration treatment using the fixed surfaces is also possible and may provide a lighter weight and less complex method of vibration control, particularly in the airplane cruise mode.

The reduction of vibratory loads on a helicopter has been examined by the helicopter industry for many years. As a result, several methods of reducing vibrations have been identified. However, it is not certain at this time how these methods can be used concurrently to generate the maximum amount of vibration reduction. For this reason, the active and passive methods for vibration reduction should be examined with an eye to implementing several of these methods simultaneously.

A3.6.2 Noise Due to Vibration

The primary cause of the low-frequency internal noise in airplane mode is pressure waves generated by the passage of each blade in close proximity to the fuselage. These waves cause a local excitation (vibration) of the airframe structure, leading to transmission of the noise to the aircraft interior. An approach to minimizing this blade passage noise is to vibrate a localized area of

the structure to cancel out the pressure waves. In addition, unsteady aerodynamic and inertial loads, primarily from the rotor hub, drive the dominant airframe structural response. Vibration can be reduced by active vibration reduction techniques independent of the blade passage low-frequency noise.

A3.7 Operational Procedures as Related to Infrastructure

A3.7.1 Operational Procedures

The CTR represents a radical new configuration for commercial service. It is the first time since the certification of the DC-3 that the commercial sector has been given the opportunity to establish operational procedures and an Air Traffic Control (ATC) System that would be optimized around a new aircraft configuration. Therefore, there may be an opportunity here to avoid the usual incremental approach to operating procedures when a new aircraft is introduced. Because of the radical new configuration and the new infrastructure required, it is anticipated that refinements to the existing system could accommodate the performance characteristics of the new vehicle. The existing operational procedures for helicopter and turboprop operations should be analyzed and comparisons drawn for the CTR aircraft.

The integration of the tiltrotor aircraft into the national transportation system should include flight operation in forward flight mode (analogous to the turboprop) underneath large commercial transports (28,000 feet and under) and nominally above helicopter flight patterns.

A smooth integration of the CTR aircraft into the national transportation system will require the establishment of unique operating procedures. These operating procedures must encompass the integration of the aircraft with fixed-wing aircraft, flight profiles while transitioning to and from vertical flight, and hover operations. In addition, research should focus on the need for an integrated flight deck that is complimentary with the air and ground infrastructure systems. Furthermore, research topics should include human factors engineering, flight deck design, mock-ups and user evaluations, flight simulations, and critical hardware demonstrations.

A3.7.2 Infrastructure

The construction of vertiports is necessary to facilitate the emergence of a strong CTR sector in the national economy. The infrastructure required to support the CTR aircraft has been studied by another subcommittee of the Civil Tiltrotor Development Advisory Committee (CTRDAC). This group advocates a master plan that should be developed outlining the scope and character of the facilities required by a community that wishes to become part of the CTR transportation system. In addition, recommendations are made about the most desirable method for financing these facilities. The master plan should recommend development in a logical sequence and justify the development from a technical and economic point of view. A key requirement in developing a master plan is an estimate of the future volumes of traffic. This estimate must then be converted into physical requirements to ensure the introduction of the proper infrastructure.

The location of vertiports has relatively few limitations. It is estimated that vertiports will need to be in the range of 10 to 30 acres of land for the vertiport terminal and Touchdown and Lift-Off (TLOF) surface, depending on number of passenger gates and anticipated flight frequency. In addition, a typical noise sensitive land area within a 65 DNL contour will be up to approximately 120 acres, also dependent on flight operations.

The challenges that may arise due to the incorporation of vertiport operations into the web of metropolitan life must be addressed. Research is required into the restrictions imposed by local zoning ordinances. The external noise level standards for aircraft operations are unique for each community. The vertiport/community relationship is key to the success of the CTR program. The opportunity is presented to implement an economical vertiport facility that ensures protection for both the vertiport and the community.

An important study that deserves special attention is the Southwest Region Vertiport Feasibility Study. This effort was sponsored by the Texas Department of Transportation and was conducted by The University of Texas at Arlington. It was published in 1991. This study examines the role of the emerging tiltrotor technology in transporting short-haul passengers between major population centers, thereby reducing congestion at the major airports. This study examines market demand, economic impact, and the financial viability of using tiltrotor aircraft and a system of vertiports to transport short-haul passengers.

The primary advantage of a vertiport system is that by flying into and out of a Central Business District (CBD), considerable time and expense can be saved compared to conventional fixed-wing airline service. This is because the trip time from a CBD to the airport, and all of the associated costs, are either reduced or eliminated. Survey results showed that many business travelers currently initiate and end travel from their residence, instead of their CBD office, because of time constraints. It is important to provide benefits of sufficient value to induce the traveler to choose the vertiport service over existing airline service. In addition, it is important to ensure that sufficient revenues can be generated to make the service economically feasible.

In order to assess the feasibility of the vertiport and the vertiport system development, five technical feasibility elements were analyzed. The five elements are physical, functional, operational, economical, and environmental feasibility. A synthesis of the five elements and their interrelationships serves to establish a framework for feasibility. A sixth element, political feasibility, was identified as critical to the success of a vertiport system. The political element is a factor of location, timing, and competition with other area projects and priorities.

Physical feasibility includes the capability of the existing site configuration, topography, utilities, and structures to accommodate the developmental needs of the vertiport within acceptable costs and environmental parameters. Functional feasibility is the capability for a vertiport layout and location to efficiently accommodate the functional relationships necessary for facility needs, capacity, access requirements, and functional expansion. Operational feasibility involves the factors that are necessary to accommodate tiltrotor operations at an airport with respect to airspace, operational surfaces and clearances, rollway lengths, touchdown pads, and appropriate navigational aids.

The fourth area of technical feasibility is that of economics. The consideration of the capital expenditures necessary to achieve the operational and development scenarios are the focus of economic feasibility. It examines the operating and maintenance costs of developmental scenarios along with the projection of potential revenue generation capabilities. The value of economic impact on a local area in terms of construction and operations also plays into the equation of vertiport feasibility.

The final area of technical feasibility is the analysis of the environmental consequences set forth in the National Environmental Protection Act (NEPA) and the FAA guidance, including noise and land compatibility. Land use compatibility will likely be the strongest environmental consideration. If vertiports are to be located near user residences, noise and residential development issues must be addressed.

One of the most important factors that should be considered in developing infrastructure concepts is that the development of the infrastructure proposed here would also greatly facilitate the operation of conventional helicopters in commercial service. It is strongly recommended that this possibility be factored into the economic feasibility calculations. There is a possibility that if this factor is properly taken into account, the economics for developing the infrastructure may turn out to be more favorable. Therefore, the decision to go ahead with infrastructure development could be made at an earlier time.

The creation of a master plan for the development of vertiports involves an extensive amount of input from planners, politicians, Federal, state, and local agencies, users, and potential operators. The feasibility elements were studied to help define the feasibility of the vertiport and the vertiport system. The vertiport system is necessary to facilitate the emergence of a strong CTR sector in the national economy.

A3.8 Alternative Concept Designs for the CTR Aircraft

An alternative concept that has been developed is the Variable Diameter Tilt-Rotor (VDTR). One manufacturer, working in combination with NASA, is investigating the technical feasibility of an advanced VDTR. The VDTR design is a two-segment telescoping blade actuated by an internal screw. The telescoping allows retraction at full rotational speed if desired without introducing bending loads in any one direction. The design has been tested at 1/6 scale in a wind tunnel and has demonstrated high levels of performance and enhanced OEI power and thrust margins due to its helicopter mode, low disk loading design. Numerous potential benefits to this design include lower autorotative touchdown speeds, greater payload range capabilities at high altitude/temperature conditions, greater operational flexibility, and a reduction in external and internal noise levels. Research work is ongoing to develop this concept for the Short-Haul Civil Tiltrotor Program. It is one of several being investigated in this program.

One manufacturer advocates the increased diameter in hover mode because the rotor thrust in hover must lift the entire weight of the vehicle including the vertical drag due to the download from the rotors. The company cites an increase in performance due to the smaller diameter in cruise, noting that the wing carries the weight and the rotor thrust required is a small fraction of the gross weight. It has been suggested that the VDTR, although only in the design phase, more nearly optimizes performance for both flight modes than is currently being achieved with the conventional fixed-diameter tiltrotor design.

Additionally, it has been demonstrated that the two rotors in close side-by-side proximity, as in the hover mode of the VDTR, lead to a beneficial "interference" effect. This result of this effect is that significantly less power is required for the two rotors as a system than if the rotor disks were not in close proximity. Given the relatively small gap separating the rotor disks in hover mode, the VDTR is able to take advantage of this phenomenon.

Perhaps the most significant result of the VDTR design study is the autorotation capability of the vehicle at full gross weight. The manufacturer states that once the rotor is in the helicopter mode at maximum diameter, the aircraft rate of descent will be less than that with a conventional rotor in the case of complete engine failure. This results from a lower disk loading and reduced chord that minimizes the effects of inboard stall that occurs with a high-twist blade in autorotation.

An effective measure of tiltrotor acoustic performance is the acoustic footprint during takeoff. The flight trajectory of the aircraft and the noise signature of the rotor system are both important factors. As the conventional CTR design and the VDTR design have similar tip speeds in hover, the noise signatures are expected to be similar. Furthermore, glide slope angles at both approach and landing are expected to be approximately equal for the two design configurations because they are limited by pilot visibility and aircraft weight rather than aircraft performance.

It is important to note that there are some negative aspects of the VDTR design. Compared to the conventional tiltrotor design, the additional mechanisms needed to extend and retract the blades imposes about a 20 percent increase in rotor system weight for the same tip speed. Furthermore, the complexity of the VDTR hub presents major reliability and maintainability issues. Finally, the VDTR design is further complicated by the all-weather operations constraints. When incorporating any component in aircraft design that entails greater complexity than an alternative component, the reliability, maintainability, and safety considerations are obviously very important.

It is the belief of one manufacturer that despite the objective of industry competitors to keep designs as simple as possible in order to minimize maintenance, history has shown that aircraft have become more complex with time. This is primarily due to performance benefits that are derived from the use of increased complexity. However, a detailed evaluation of reliability, maintainability, and safety attributes of the VDTR must await the completion of the full-scale design, at which time the manufacturer hopes to prove that complexity is simply the price of improved performance.

An additional approach considered by the CTRDAC Aircraft Subcommittee was the substitution of the tiltwing for the tiltrotor concept. In a tiltwing aircraft, the entire wing of the airplane is rotated rather than just the engine nacelles, as in the tiltrotor aircraft. During the 1960s, an experimental aircraft called the XC-142 was developed. Several of these were built and an experimental program was conducted to determine the characteristics of the aircraft. At about the same time, the first experimental tiltrotor aircraft, the XV-3, was being tested. In fact, the XV-3 preceded the XC-142 by a few years. Both flight test programs were thoroughly evaluated in 1969 by a group established by then NASA Administrator Thomas O. Paine. A decision was reached that the tiltrotor concept was more promising for a number of potential applications. Ultimately, this decision lead to the development of the XV-15 tiltrotor experimental aircraft. This program was extremely successful and the experimental results obtained were the major factor in the initiation of the V-22 program. Furthermore, it is, of course, the V-22 program that led to the establishment of the CTRDAC to determine the civil applications of the tiltrotor principle.

The Aircraft Subcommittee was briefed on the tiltwing concept during its deliberations. It is the considered opinion of the subcommittee that there is no reason to revisit the tiltwing concept as a possible substitute for the tiltrotor aircraft for the civilian missions now being contemplated by the CTRDAC.

A4.0 Historical Analogy to Justify Involvement by the Federal Government

The question is often raised whether the Federal Government should sponsor the development of what will eventually become a commercial enterprise. The best way to answer this question is look at history. The Federal Government has played a vital role in the integration of technological advancements in the U.S. ever since the Republic was founded. This role has traditionally been initial financial support in the form of Government loans and/or subsidies. Three of the most significant advancements that used initial Federal financial backing were the railroad system, the commercial aviation system and the telecommunications system.

Building the transcontinental railroad was so costly and risky that it required Government subsidies. The extension of rails into thinly populated regions was unprofitable until the areas could be built up. Private promoters were unwilling to suffer heavy initial losses. Congress, which was impressed by arguments supporting military and postal needs, began to liberally advance money loans and enormous acreage paralleling the tracks in 1862.

The Central Pacific and Union Pacific Rail were granted generous Federal loans, ranging from $16,000 per mile on the flat prairie to $48,000 per mile in mountainous country. This Federal monetary support was a vital instrument that led to the completion of the transcontinental rail system.

The accomplishments of the railroad were surpassed in just half a century by commercial aviation. The history of air transportation is a saga of chances taken or ignored, profits gained or lost, and technical developments introduced or passed up. In little less than half a century from the pioneering flight of the Wright brothers, U.S. airliners flew a greater number of annual air passenger miles than the railroad passenger miles covered by the Pullman cars. This increase in commercial aviation brought about an increase in employment. The Federal Government played a key role in the success of the commercial air transportation system.

In 1925, Congress passed the Air Mail Act, popularly known as the Kelly Act. The Kelly Act approved Federal subsidies for air mail service. The Government paid individual companies to haul the mail. The air mail service was the initial "bread and butter" of commercial aviation. This was of crucial importance to the subsequent growth of the U.S. air transportation market as it encouraged private companies to enter the air transportation commerce field.

The role of the Federal Government in the integration of technological advancements has not been restricted to the transportation industry. The telecommunications industry also benefited from initial financial support from the Federal Government. The advent of space communications through the use of satellites and the formation of an international cooperative organization, INTELSAT, to develop and provide global telecommunications revolutionized the ability of the world to communicate.

The need for an organization like INTELSAT arose from the U.S space program, in particular the National Aeronautics and Space Administration (NASA) Apollo Program aimed at putting man on the moon. This program could only be implemented successfully if there were reliable telecommunications between the spacecraft and ground controls in the U.S. There was a technical need for satellites and a political need to provide the service internationally, quickly, efficiently, and coopera-

tively. It should also be noted that there were many business interests at stake in support of the space program and all its expected benefits to the U.S.

Congress passed the Communications Satellite Act in August 1962 with the prime objective of instituting an international telecommunications network. The management of the INTELSAT system was performed by COMSAT, which was incorporated as a private company in February 1963 with a mixture of public and private funding and objectives. The U.S. signatory to the organization, COMSAT, created a brilliantly successful program. The U.S. Government authorized NASA to provide launch services at basic cost wherein the enormous development cost was borne entirely by the U.S. taxpayer. It may be stated that without these contributions, worldwide communications would not be where they are today.

The role of the Federal Government in the integration of these technological advancements into society was clearly of critical importance. Without the financial support of the Government, these advancements might never have been achieved. Furthermore, the Federal Government has an obligation to continue to support new technological advancements to ensure their successful integration into society. The CTR is one such advancement that, if financially supported by the Federal Government, will lead to beneficial short-haul transportation for the people of this country in addition to positive opportunities for private business growth.

A5.0 Recommended Research Program

This report attempts to outline and justify a research program that must be conducted before a civil tiltrotor (CTR) of commercial value can be developed. The program focuses on those things that must be done in addition to what will be learned from the military flight experience with the V-22. The Civil Tiltrotor Development Advisory Committee (CTRDAC) Aircraft Subcommittee recommends that a research program be initially aimed at the eventual creation of a CTR aircraft that can be certificated and put into commercial operation by the year 2007. The Aircraft Subcommittee therefore recommends a three-phase program aimed at the creation of a CTR transport aircraft that incorporates many, if not all, of the features of the National Aeronautics and Space Administration (NASA) and contractor programs. The program is described below.

A5.1 Phase A

The first phase of the research program would be to enhance the currently planned NASA research program dedicated to tiltrotor technology research. The currently approved program, that has been underway since 1994, is funded at a level of $63 million through 2001. The focus of this program is on noise research in wind tunnels using scale-model rotors, contingency power engine research, and commercial flight deck research using flight simulators and man-machine interface workload analysis models. Work on rotors using computational fluid dynamics is also part of this program.

This program would be augmented by another $220 million and combined with the existing Short-Haul Civil Tiltrotor program so that a new program would be defined with a shorter overall schedule and a total cost of $283 million for the new Phase A as defined here. The additional $220 million in funding would be used to develop an advanced full-scale rotor system tested in the wind tunnel with follow-on flight tests as appropriate. It would also be used to develop the operational software and hardware for a commercial cockpit, a reliable drive system, full-scale engine ground demonstration of contingency engine power, and composite wing, fuselage and empennage large-scale component tests (thin gauge and dynamically tuned structures). Also included would be work on internal noise reduction methods.

A limited amount of flight research would also be a part of this program. This work would be performed with existing helicopters, the XV-15, and perhaps even with military V-22 aircraft. The Aircraft Subcommittee recommends that Phase A of the program outlined here be put in place and executed. Detailed cost estimates for the Phase A program are shown in figure A5.1-1.

A5.2 Phase B

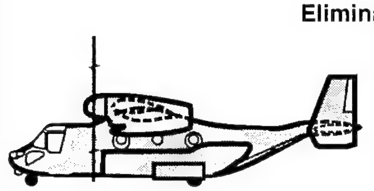
It is clear from the questions that must be answered that extensive flight research will be necessary in order to create a commercial CTR aircraft. The Aircraft Subcommittee recommends a flight research program using a suitably modified V-22 aircraft. Although this airplane would not be a commercial prototype, there is much to be learned from a flight program using such an airplane. The modifications that would be performed on a standard V-22 taken off the existing military production line are outlined in figure A5.2-1. These are quite extensive, and it is estimated that they would require spending approximately $210 million.

The $210 million aircraft modification program proposed here would begin in 1998 with the

Program	Time Line	Cost	Description
Ongoing NASA research	1994 - 2001	$63 million	• Currently funded. • Model scale testing of low-noise proprotor technology, advanced cockpit, increased engine contingency power. • Schedule would be compressed to 1994-1999 time frame to support next phase.
Augmented program	1997 - 2000	$220 million	$80 million— • Advanced proprotor design, wind tunnel test and early flight test with appropriate flight test vehicle (1998 start).
			$20 million— • Advanced vehicle management system development using simulation and/or flight testing (1997 start).
			$70 million— • Drive train and contingency engine propulsion concepts demonstrated in full scale integrated ground tests (1997 start).
			$50 million— • Composite wing, fuselage, and empennage structures concepts validated in large-scale component tests (thin gauge and dynamically tuned structures). • Development of internal noise/vibration reduction mechanism (1998 start).
		Total $283 million	

NOTES:
- The ongoing NASA program is already funded for $63 million
- If the augmented program is funded, the ongoing and augmented programs would be combined into a comprehensive, integrated, single program for a total combined cost of $283 million
- In the augmented program, the level of industry participation will determine how many rotors and what scale will be tested in the wind tunnel and in flight test. The data from this portion could be used to support a range of civil tiltrotor sizes (from 9 to 40 seats)
- The transmission would be developed for the optimum configuration that will benefit the next phase of this program (V-22 flight demo). The XV-15 flights would be with a minimum modification to the existing transmission

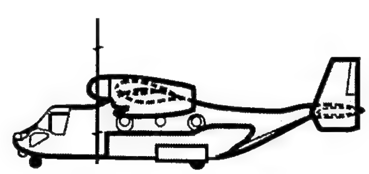
Figure A5.1-1 Phase A Research and Development



V-22 EMD aircraft

Eliminate
- Three-bladed rotor/controls
- Military floor/tie downs/buffer boards
- Military crew seats/armor buckets
- Military controls/displays
- Troop seats
- Ramp/fittings/hydraulics
- Military avionics/FLIR/multi-mode radar
- Refueling probe/associated systems
- EAPS fans
- NBC filters
- Wing stow motors
- Blade deice generators
- OBOGS/OBIGGS
- HIFR system
- Cargo hooks, beams, doors
- Mission equipment (rescue hoist, rafts, etc.)
- Winch

Add
- Five-bladed rotor/controls
- Commercial floor
- Commercial crew seats
- Commercial controls/displays
- Commercial interior in front section (9 seats)
- Skin over ramp area
- Windows in front section
- Partition/door at back of front section



Commercial demonstrator

Figure A5.2-1 V-22 EMD Aircraft Modifications for Commercial Demonstration

augmentation funds for the Phase B program. The modified aircraft would perform a $75 million demonstration flight program in the years 2001 to 2003.

The measurement of external noise with a rotor configuration designed for lower noise would have first priority in the flight research program. This would include objective noise measurements using ground-based microphone arrays, subjective measurements using human subjects, and the development of methods to reduce the measured and perceived noise levels. A second priority would be to obtain evaluations by many different pilots of the modified V-22 aircraft. These would be done using the Cooper-Harper pilot rating scale. They would be compared with the flight simulation results obtained in Phase A of the program. These evaluations would focus on transition from helicopter to airplane mode, the flying qualities of the aircraft, and on experiments with different kinds of avionics equipment.

In addition to these experiments, the modified V-22 aircraft would be used for experiments related to infrastructure development for a CTR-based air transportation system. This work would probably be performed at prototype vertiports built by the Federal Aviation Administration (FAA). Investigations would include lighting patterns on the ground for night time and instrument flight rules (IFR) operations, satellite-based navigation systems, and alternative air traffic procedures. Finally, there would be regional system demonstrations in various parts of the country to test the local viability of the transportation system based on CTR aircraft. Because the Aircraft Subcommittee believes that flight research is essential, we recommend that Phase B of the program be adopted and executed. The detailed funding profile for Phase B of the program is shown in figure 5.2-1.

A5.3 Phase C

It is probable that the execution of Phases A and B of the program will be enough to answer the open questions that have been identified in Section A2.0 of this report. These phases will be completed in the early years of the next century. Should the private sector decide at that time to go ahead with the creation of a commercial CTR aircraft, and should the necessary public investments be made to create the infrastructure, then such development would proceed.

The industry-developed CTR2000 configuration is a vision of such a vehicle. The major objective of Phase C of the program would be to develop and certificate a production vehicle (figure A5.3-1).

Program	Time Line	Cost	Description
CTR flight demonstrator	1998 - 2001	$210 million	Highly modified V-22 development, assembly, and initial flight operations: • Advanced proprotor and drive system technology from previous program • Commercial 9-passenger cabin • Upgraded cockpit
	2001 - 2003	$75 million	Flight demo of modified V-22. Assumes flight demo cost of $2 million per month for 3 years
Total $285 million			

Figure A5.2-2 Phase B Research and Development

Program	Time Line	Cost	Description
CTR production prototype	2003 - 2008	$1.2 billion	Development, assembly, and testing of a pre-production prototype vehicle, incorporating latest technology

Figure A5.3-1 Phase C Development

At this time, it is too early to make an accurate cost estimate of Phase C to produce a 40-passenger vehicle. However, it is likely that we would be looking at about $1.2 billion dollars spent over approximately 5 years to create the CTR2000 commercial prototype aircraft. The CTRDAC Aircraft Subcommittee recommends that a thorough study of Phase C be made to prepare for the decision when the time comes.

Civil Tiltrotor Development Advisory Committee

Report of the Environmental and Safety Subcommittee

Safety Issues

CTRDAC Environment and Safety Subcommittee

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CTRDAC Environmental & Safety Subcommittee Report

Safety Issues

CTRDAC Environmental & Safety Subcommittee Report
Safety Issues

B1.0 Executive Summary

B1.1 Purpose

The Civil Tiltrotor Development Advisory Committee (CTRDAC) was established by the U.S. Department of Transportation as directed by Congress under the provisions of Public Law 102-581, Airport and Airway Safety, Capacity, Noise Improvement, and Intermodal Transportation Act of 1992. The CTRDAC Environment/Safety Subcommittee was tasked with identifying and investigating environmental and safety issues. This report examines the safety considerations associated with the development and operation of the civil tiltrotor (CTR). The Subcommittee also considered environmental issues related to the development and introduction of CTR. The results are contained in the next section of this technical supplement.

B1.2 Background

The CTRDAC Environment and Safety Subcommittee was tasked with identifying and investigating safety issues (reference 1), including an estimation of the safety characteristics of CTR operations and an analysis of the potential for CTR to operate safely in all weather conditions. The Subcommittee was also tasked with providing details on safety characteristics to the Economics Subcommittee to help determine economic viability.

Tiltrotor technology has been successfully developed over the last three decades in a sustained cooperative effort by U.S. industry and Government. The XV-3 and XV-15 tiltrotor research aircraft programs contributed to the successful design of the military V-22 multi-mission tiltrotor now in final stages of engineering, manufacturing, and development (EMD). The V-22 is scheduled for production later in this decade.

V-22 production funds have been requested in the fiscal year 1996 budget for all deliveries beginning in 1999. The V-22 technology base also has potential application to the development of CTR. The CTRDAC has addressed a wide range of issues related to the potential development and implementation of CTR operation. In addition to safety considerations, the CTRDAC Subcommittees have evaluated the issues related to CTR development, environment, infrastructure, and economics.

The CTRDAC is interested in CTR technology and, in particular, the public benefits that can be expected from this type of aircraft. In the future, it is anticipated that various sizes of CTRs may perform a wide variety of missions, including emergency medical service (EMS) and corporate/executive transportation. However, the analysis of the Economic Subcommittee has indicated that the largest public benefits from the CTR will probably result from a growth in aviation capacity and a reduction in airport delay and congestion. These benefits are expected with the introduction of CTR as a scheduled air carrier aircraft. When CTRDAC analyses required the consideration of specific aircraft characteristics, the vehicle used was the 40-passenger CTR2000 (figure B1.2-1).

B1.3 Results in Brief

A CTR can be developed and operated as a safe element of the national transportation system. CTR aircraft share many safety attributes with both fixed-wing aircraft and helicopters. They also have safety features that are unique to the CTR design. As will be discussed, tiltrotor mishaps

Performance Summary	
Maximum vertical takeoff gross weight	43,150 lb at 2,000 feet/ISA +20 degrees C at sea level/standard day
Operating empty weight	28,623 lb
Design range	600 nm with full passenger load and IFR fuel reserves
Maximum cruise speed	350 knots at 25,000 ft
Best range airspeed	315 knots at 30,000 ft
Service ceiling	32,000 ft
Maximum range	>1,000 nm with IFR reserves
Installed Engine Characteristics	
Engine number and type	Two IHPTET turboshaft
Maximum takeoff rating	7,260 SHP/engine at sea level/standard
30 - second contingency rating	8,820 SHP/engine at sea level/standard 7,800 SHP/engine at 2,000 ft/ISA +20 degrees C
Physical Characteristics	
Rotor diameter (each)	36.3 ft
Fuselage length	62.4 ft
Height	23.6 ft
Width (rotors turning)	86.2 ft
Number of cockpit crew seats	2
Number of passenger seats	40 plus 1 attendant
Installed horsepower	7,260 shaft horsepower/engine at sea level/standard maximum static

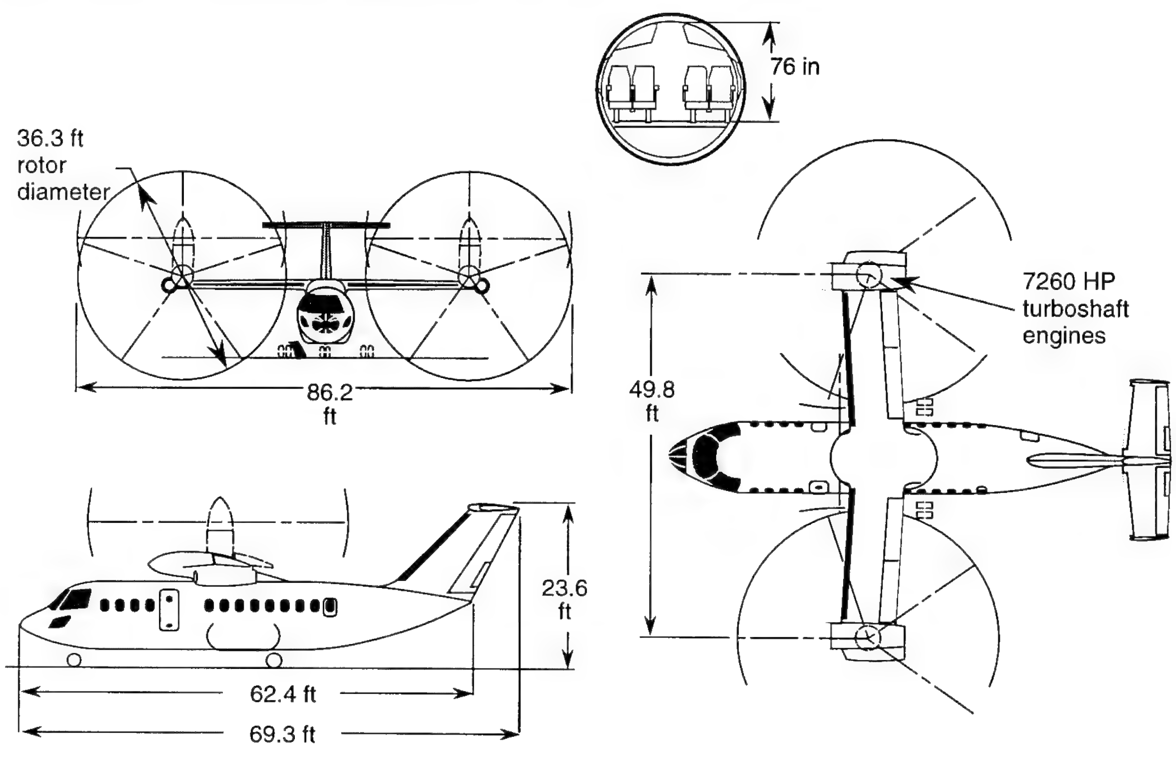

Figure B1.2-1 CTR2000 Characteristics

were reviewed and the most important conclusion reached is that **none were attributed to the tiltrotor concept**. Each production/maintenance mistake could also have occurred on either a turboprop aircraft or helicopter.

As with other new aircraft, the CTR can be expected to benefit from emerging technologies such as fly-by-wire (FBW) flight controls, composites, the global positioning system (GPS) for precise navigation, and systems condition and usage monitoring systems. In order to keep up with these new technologies, while developing the interim powered-lift standards that apply to the type certification of CTR, there is a need for the Federal Aviation Administration (FAA) to continue the training of Designated Engineering Representatives (DER) and National Resource Specialist (NRS) personnel.

Finally, it is important that the flight characteristics and flight deck design of the CTR allow transition training to CTR for instrument-rated pilots from either the fixed-wing or helicopter communities.

B1.4 Concluding Remarks

Although a CTR will bring together a number of new or emerging technologies in one new vehicle, virtually all of these new technologies will be proven in other new aircraft by the time a CTR is introduced. With well directed research and a rigorous certification process, there are no safety impediments to the introduction of a CTR.

B1.5 Key Recommendations

CTR research should be completed before the year 2003 to reduce the risks of failure or delay in the initial CTR certification program. At a minimum, this effort should include research in:

- Propulsion system (engine/proprotor).
- Designs for power-off landing capabilities.
- FBW technology.
- System condition and usage monitoring technology.
- Human factors for CTR flight deck design.
- CTR training requirements.
- Rotorwash and wake vortex impacts.

The FAA should review and revise current operations certification regulations that would be applicable to a CTR in scheduled air carrier service to provide the highest level of safety.

The FAA should continue to ensure rigor in the DER/NRS safety, design, and certification processes by acquiring familiarity and experience with the new technologies that may be used in the CTR.

The certification of FBW control systems is one of the areas requiring further definition in Part XX, Interim Airworthiness Criteria for Powered-Lift Transport Category Aircraft (reference 2). Software-based systems design is also an area where the FAA must develop expertise to provide appropriate oversight. The FAA should ensure that these needs are met during the ongoing application and refinement of these certification standards.

The air traffic control (ATC) system should be extended to include airspace infrastructure with instrument approaches/departures for CTR operations using GPS and differential GPS (DGPS).

B2.0 Introduction

The safe operation of any civil aircraft is determined by its design and construction, the training of its maintenance and flight crews, the operating standards under which it is used, and the strict adherence to these operating standards by the operator. The civil tiltrotor (CTR) design has evolved from both the turbine-powered helicopter and the multi-engine turboprop airplane. Consequently, many safety issues incorporated into these two types of aircraft are also central to the CTR design philosophy. The history of aviation contains many examples of technology transfer from military to civil programs. New technologies that are likely to be incorporated into a CTR, such as fly-by-wire (FBW) control systems and composite construction, will benefit from experience gained in military and civil use and from continuing civil research programs. Early prototype aircraft designs are often tested in military service before modifications are applied to the civil derivative aircraft that incorporate safety/reliability lessons learned. Augmented by applied research programs, the result has been safe and highly reliable civil transport aircraft designs. As in any new aircraft development, these military legacies and the accompanying civil developmental research programs will strengthen the aircraft type certification process. This, in turn, will lead to operating standards that are optimized through flight research activities to enhance safety and minimize environmental impact of the CTR.

To date, no CTR aircraft has been certificated for civil transport use. Given the impact that rigorous type certification standards have on safety, it is essential that the CTR planned for scheduled air carrier service be type certificated to the highest standard of airworthiness. Currently, the airworthiness standards for powered-lift aircraft are in an interim, or draft, status. These standards, the Interim Airworthiness Criteria, Powered-Lift Transport Category Aircraft, will be developed further by the Federal Aviation Administration (FAA) with the help of industry as further experience in the design, development, certification process for CTR is gained. As is the general practice, an interim airworthiness criteria is not finalized until an aircraft has been certificated using the criteria.

To date, no one has been certificated by the FAA as a tiltrotor pilot or instructor. Recently, however, the FAA published a notice of proposed rulemaking to Federal Aviation Regulation (FAR) 61, Certification: Pilots and Flight Instructors (reference 3). Of particular interest is the proposed addition of powered-lift aircraft as a new category for certification of private, commercial, and airline pilots and for flight instructor and ground instructor certificates. As CTR aircraft and simulators are certificated and become more widely available, these proposed rules will allow pilots and instructors to be certificated.

Operating standards ensure high safety levels by setting requirements for the flight operations of the aircraft and for the training and qualifications of flight and maintenance personnel. Aviation accident statistics maintained by the FAA and the National Transportation Safety Board (NTSB) clearly indicate that overall aircraft operational safety improves not only with increased rigor in design (airworthiness) but also in operating standards. The most rigorous operating standards are Title 14 of the Code of Federal Regulations (14 CFR) Part 121. It is recommended that the FAA develop an appropriate CTR operations standard that will achieve the highest level of safety appropriate to the operations being conducted.

B3.0 Tiltrotor Design Features

The tiltrotor is a versatile aircraft capable of operating from hover to airspeeds of 300 knots or more. The design represents a combination of characteristics of multi-engine turboprops and turbine-powered helicopters.

The most advantageous characteristic of the tiltrotor is the ability to tilt the proprotors from a horizontal to a vertical position, i.e., convert from a helicopter to an airplane and back again. This process, called conversion, gives the tiltrotor the best features of both helicopter and fixed-wing turboprop aircraft. The airplane cruise mode provides safety advantages of speed, altitude, and range. The helicopter mode provides safety advantages of precision approaches at low speed without the danger of stalling.

Figure B3.0-1 shows the conversion sequence as the tiltrotor aircraft transitions from helicopter mode for takeoff, through conversion mode, to airplane mode for high-speed cruise. The aircraft remains fully controllable about all axes throughout the conversion sequence regardless of the acceleration or deceleration rate. It can also be flown for an extended period of time in any of the intermediate states. The allowable airspeed range for each proprotor tilt angle, known as the conversion corridor, is sufficiently large to permit great flexibility in piloting the aircraft.

A comparison of the tiltrotor with turboprop aircraft and helicopters reveals that it shares some safety features with each aircraft type while possessing additional unique safety features. These safety features cover issues such as aircraft operational limitations, structural and dynamic component reliability, and pilot workload.

B3.1 Safety Features Tiltrotors Share With Turboprop Aircraft

With its proprotors tilted full forward, the tiltrotor essentially becomes a twin-engine turboprop aircraft. This enables it to achieve the speed and range operational advantages that tiltrotors share with turboprop aircraft. Greater range and speed capability improves the prospects of reaching an alternate landing site during adverse weather operation. In fact, Federal Aviation Regulation (FAR) Part 91 and FAR Part 121 Instrument Flight Rules (IFR) requires that an aircraft carry enough fuel to complete the flight to the first airport of intended landing, fly from that airport to an alternate, and fly

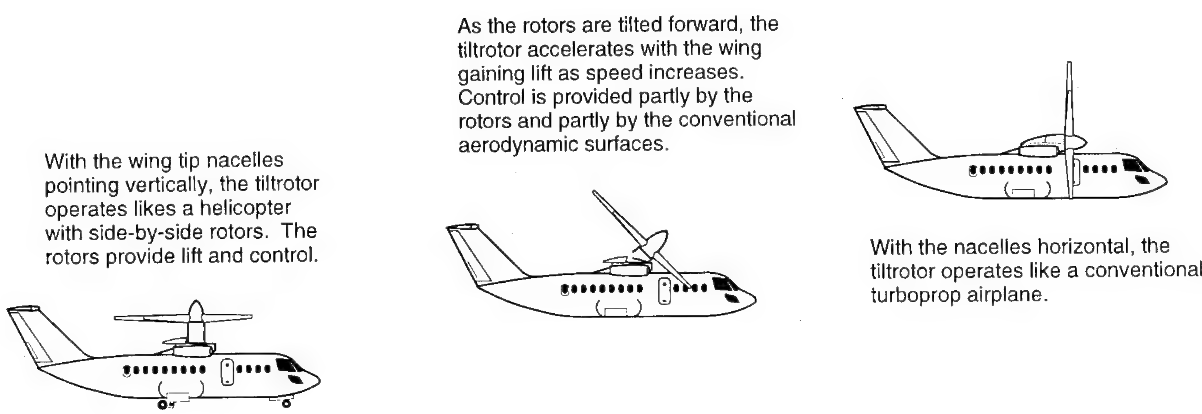

Figure B3.0-1 Tiltrotor Conversion Sequence

after that for 45 minutes at normal cruising speed. The expected performance of a civil tiltrotor (CTR) includes a 600 nautical mile (NM) maximum range with IFR reserves for a 50 NM alternate destination plus 45 minutes cruise. CTR cruise speeds between 300 and 350 knots are clearly achievable. The pressurized CTR fuselage will allow cruise flight up to at least 30,000 feet, enabling the aircraft to fly above most bad weather patterns and turbulence. Consequently, in scheduled airline service, the CTR will use IFR procedures and be flown like commuter turboprop aircraft, minimizing the risk of terrain or obstacle collisions.

Another advantage that tiltrotors share with turboprop aircraft is low vibration that enhances structural and dynamic component reliability. In airplane mode, the tiltrotor experiences low proprotor vibration and fatigue-inducing vibratory loads. Figure B3.1-1 shows a comparison of cabin vertical-axis vibration levels at cruise for helicopters, turboprops, and the V-22 tiltrotor (at 275 knots) at the appropriate frequency (reference 4). This figure shows that tiltrotor technology is highly effective at reducing the vibrations that conventional rotorcraft encounter in high-speed flight. Reducing vibratory loads means that structural components last longer. In fact, the industry rule of thumb holds that for components operating at stress levels near the fatigue threshold, a 15 percent reduction in vibratory stress can double the expected life of the component.

B3.2 Safety Features Tiltrotors Share With Turbine Multi-Engine Helicopters

Like a helicopter, a tiltrotor with its rotors horizontal is capable of hover and vertical flight. Consequently, it has no wing stall speed below which safe flight cannot be maintained. This represents a significant operational advantage that the tiltrotor shares with helicopters.

The tiltrotor low-speed and hover capabilities permit it to make slower, safer approaches than a fixed-wing turboprop. The ability to perform helicopter mode approaches gives the tiltrotor greater tolerance of the horizontal component of wind shear effects than a comparable fixed-wing aircraft. CTR vertical flight capability also produces excellent low-speed and crosswind landing capability. This advantage is emphasized in FAR Part 29 for transport helicopters that requires controllability in 17 knot winds *from any horizontal direction*. Likewise, the Interim Airworthiness Criteria for Powered-Lift Transport Category Aircraft requires 360 degree hover turn capability in no less than 20 knot winds. In fact, most rotorcraft are derived from military designs which must meet 30- to 35-knot wind requirements, also from any horizontal direction (references 5 and 6).

Another low-speed limit on multi-engine, fixed-wing aircraft is the minimum control speed. This is the lowest speed at which it is possible to control the aircraft directionally with one engine inopera-

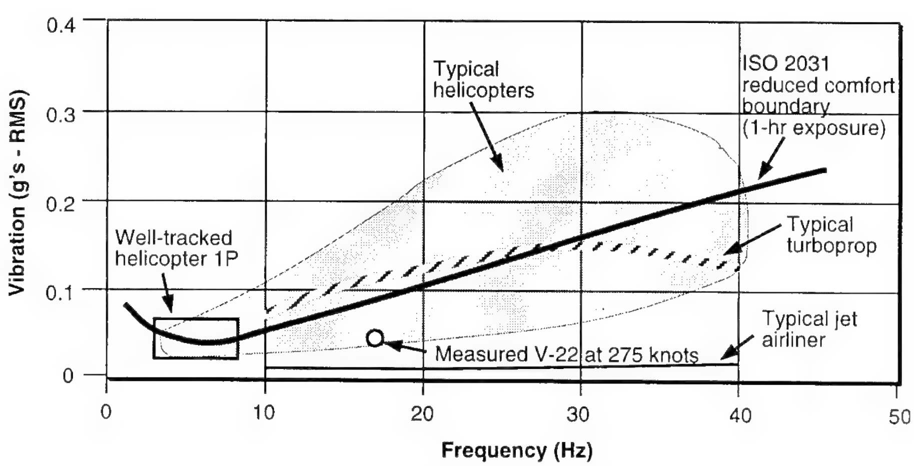

Figure B3.1-1 Cabin Vibration Levels in Cruise

tive (OEI). In the event of an engine failure, fixed-wing aircraft experience a large steady yawing moment due to thrust from the operative engine on one side of the aircraft and drag from the inoperative engine. Significant rudder control is required to offset this asymmetric thrust condition (figure B3.2-1). Multi-engine helicopters do not experience a steady yaw moment in OEI conditions because thrust is provided by the main rotor located on the center line of the aircraft. In tiltrotors, symmetric thrust is maintained by the interconnect drive shaft (ICDS) that allows the remaining engine(s) to power both proprotors equally (figure B3.2-2). This maintains aerodynamic symmetry and controllability while sharing the remaining engine power.

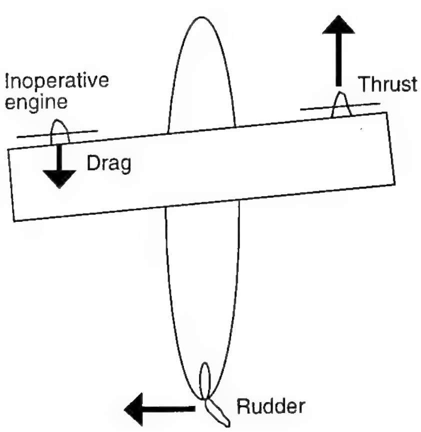

Figure B3.2-1. Fixed-Wing Aircraft OEI Asymmetric Thrust Condition

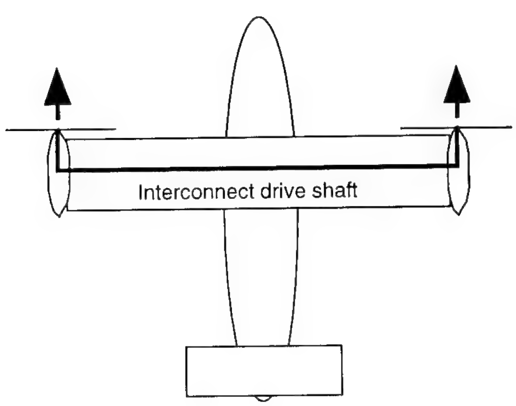

Figure B3.2-2. Interconnect Drive Shaft Ensures Thrust Equalization

Following a total power failure, the helicopter has the potential of autorotating to a safe landing. In autorotation, the steady descent of the helicopter produces an upflow of air through the rotor. With the blades at low pitch, the rotor will "windmill," providing thrust to maintain the rate of descent and rotor rotational speed. This can be thought of as a conversion of potential energy (altitude) into kinetic energy (rotor revolutions per minute (RPM)). With the engines inoperative, rotor speed from the transmission powers the electrical and hydraulic systems, ensuring operation of the flight control and flight management systems. A low-speed landing is accomplished by flaring the aircraft. This converts some of the forward speed into more rotor kinetic energy (higher rotor RPM). The collective blade pitch is then increased which decreases the rotor RPM and converts the energy of the rotor to thrust for slowing the descent and cushioning the landing.

Should a total engine power failure occur in a tiltrotor while in helicopter mode near the terminal area, the CTR would autorotate to a run-on landing in a manner similar to a heavyweight helicopter with a forward speed of 50 to 70 knots. If the power failure occurs in cruise flight (airplane mode), the CTR can make a power-off landing similar to a turboprop. Alternatively, the pilot can execute a power-off reconversion in an attempt to make an autorotation if the situation permits this maneuver.

In helicopter mode, the proprotors produce thrust and maintain RPM similar to a helicopter in autorotation. Aft movement of the nacelles by 5 to 10 degrees (to the aft stops) upon flare and touchdown adds the additional flare and deceleration capability required to make a power-off landing. This capability recognizes that CTR rotor inertia is much less than that of a traditional helicopter rotor.

Another safety feature of the tiltrotor is the ground clearance of the two proprotors. During normal ground operation with proprotors turning, the high overhead location of the horizontally positioned proprotors eliminates the possibility of personnel inadvertently contacting a spinning rotor or aircraft propeller.

B3.3 Tiltrotor-Unique Safety Advantages

In addition to the usual operational safety features and precautions taken for present civil aircraft, the tiltrotor has several characteristics that distinguish it from the helicopter and fixed-wing turboprop. These are expected to confer an additional margin of safety on its operation. The ability to directly control proprotor shaft tilt and, in turn, the primary thrust vector in a tiltrotor allows the pilot to maintain a near-level fuselage (flight deck) attitude for all flight conditions. This is a particular safety advantage in landing, where the pilot of a conventional aircraft or helicopter must contend with a pitch-up at flare or landing deceleration respectively. This sometimes represents a 15 to 20 degree pitch-up. In a tiltrotor, the pilot can control the attitude of the aircraft to maintain good external visibility.

Another desirable safety characteristic possessed by tiltrotors is their aerodynamic symmetry. Symmetry reduces the cross-coupling between controls, making the aircraft easier to fly and reducing pilot workload. For example, the two proprotors rotate in opposite directions, and the torque that each rotor applies to the fuselage is balanced. As the pilot changes thrust, the torque on each proprotor changes but the effects balance each other. If the pilot performs a vertical maneuver in hover, there is no need to make a yaw correction for each thrust change as would be required in a conventional helicopter. The absence of cross-coupling between controls reduces pilot workload and, in turn, enhances safety.

Another unique safety feature of the tiltrotor is the ICDS that permits an almost instantaneous symmetrical power transfer in the event of a single engine failure. This makes the tiltrotor aerodynamically symmetrical. As discussed earlier, an engine failure in a fixed-wing aircraft results in a steady yawing moment that must be counteracted with the rudder (figure B3.2-1). In non-tandem rotor helicopters, an engine failure results in a torque change that produces a transient yawing moment. With the ICDS in the CTR, the torque is transferred almost instantly between proprotors, eliminating both transient and steady yawing moments.

The tiltrotor design incorporates two modes of control, fixed-wing control surfaces for airplane mode flight, and proprotor controls for helicopter flight. With the tiltrotor operating in airplane mode, pitch attitude is controlled by the elevator, roll by the ailerons, and yaw by the rudders (figure B3.3-1). In helicopter mode, pitch is controlled by longitudinal cyclic which tilts the proprotor tip path plane forward and aft (figure B3.3-2). Roll is controlled by differential thrust on the two proprotors. Yaw is controlled by differential longitudinal cyclic on the proprotors.

As the tiltrotor converts from low-speed helicopter mode to high-speed airplane mode, commands to the proprotor controls are gradually phased out as the fixed-wing control surfaces become more effective. The control phasing is performed in a manner that maintains a constant level of controllability as the aircraft transitions between modes. This affords the pilot complete control of the aircraft at any nacelle angle between helicopter mode and airplane mode. Such controllability enhances safety by giving the pilot maximum flexibility in flying the aircraft.

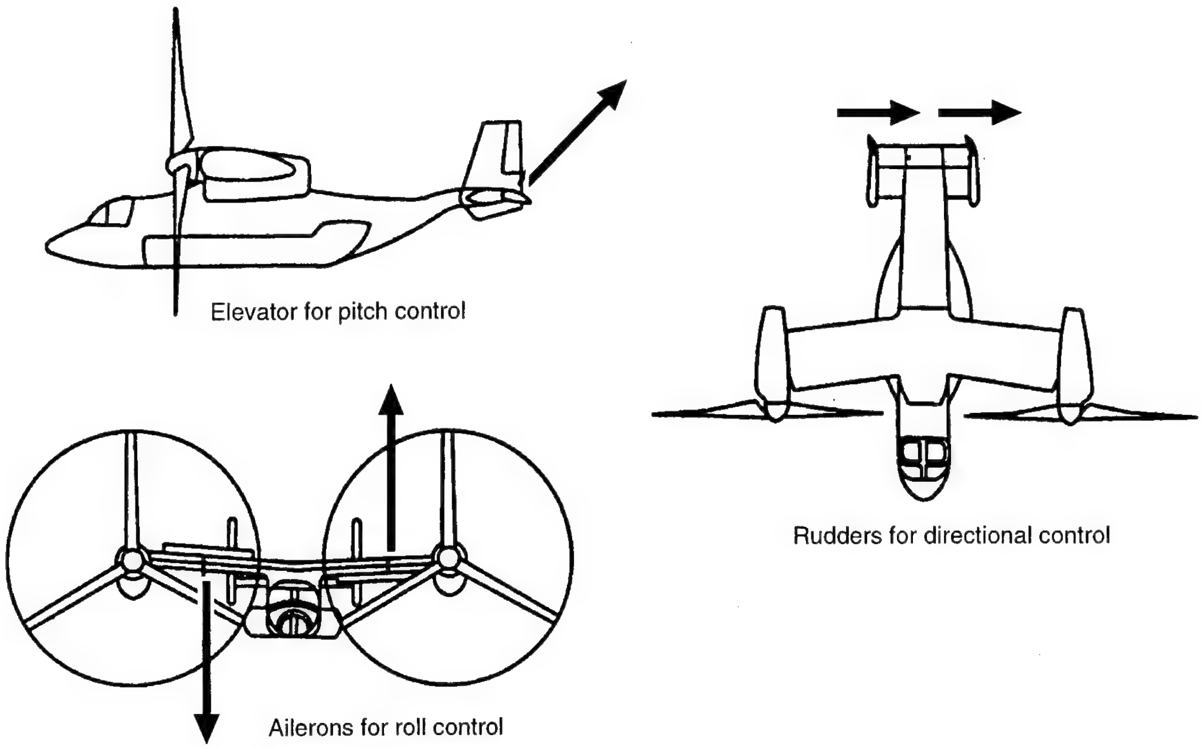

Figure B3.3-1 High-Speed Tiltrotor Control

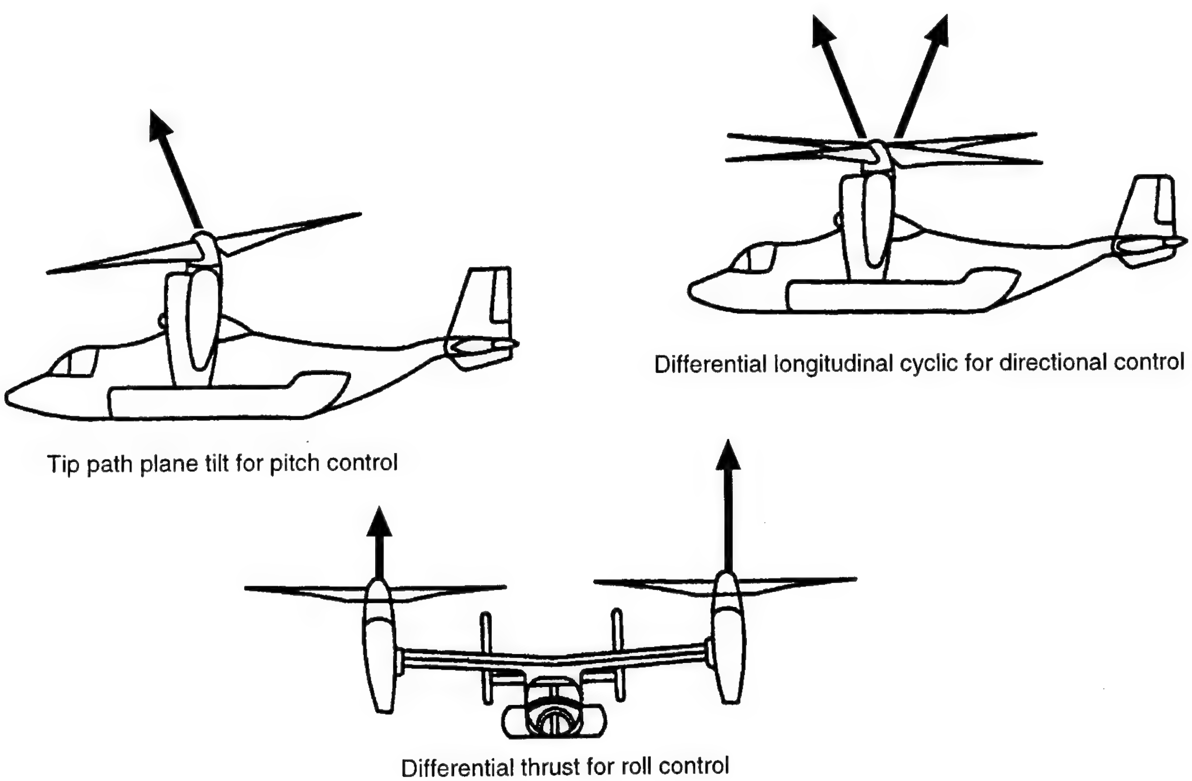

Figure B3.3-2 Low-Speed Tiltrotor Control

B4.0 Certification Criteria

Certification, as discussed in this section, covers three areas: aircraft design certification, aircrew certification, and operations certification. The focus of aircraft type certification is on the airworthiness of the vehicle in terms of flying qualities, strength requirements, design and construction, power plant, equipment, and operating limitations. Aircrew certification deals with the requirements for aircrew eligibility, aeronautical knowledge, experience and skill, and testing. Operations certification prescribes the rules governing flight operations, aircraft and equipment, weather requirements, flight crew member requirements, training, aircraft performance operating limitations, and maintenance.

B4.1 Aircraft Certification

Before introducing a new aircraft into commercial service, manufacturers must obtain an Federal Aviation Administration (FAA) Type Certificate, signifying that the basic design and systems meet minimum airworthiness standards. In practice, FAA involvement in the certification of a new aircraft starts well before the first prototype aircraft ever flies. Throughout the design process, the manufacturer must supply the FAA with detailed plans, drawings, test plans and laboratory test reports, and analyses to demonstrate that the aircraft complies with FAA design requirements.

The certification process depends heavily on the expertise of the FAA Designated Engineering Representatives (DER). DERs are manufacturer employees who act as surrogates of the FAA in approving certification tests and analyses. The FAA certification staff oversees these designees, who are specialists in their respective technology areas.

A recent General Accounting Office (GAO) report (reference 7) raises a concern over the lack of FAA experience in new technologies, stating "FAA staff have sometimes not understood the new technologies that they have been asked to certify." The GAO report cites a 1980 National Academy of Sciences report (reference 8) stating that the "FAA's system of delegation was sound but warned that the technical competence of FAA's staff was falling far behind that of manufacturer's designees, to the point that the agency's oversight was becoming superficial."

In an attempt to improve staff competence, the FAA established the National Resource Specialist (NRS) Program that develops in-house experts in such subjects as crash dynamics, composite materials, and advanced avionics. In a response to the GAO report (reference 7), the Aerospace Industries Association of America (AIAA) recommends that the "NRS for a particular specialty should maintain general oversight of a technology and as it approaches a maturing stage, the NRS should begin to lead the development of reasonable standards for certifying designs with the new technology. Also, the NRS should take a significant role in bringing the FAA certification staff 'up to speed'."

The following paragraphs describe the proposed powered-lift certification (safety) standards that would apply to a civil tiltrotor (CTR). Those areas that require further study before airworthiness criteria can be defined are identified. Other new technologies likely to be found in a CTR, that will present a challenge to the FAA certification staff, are also outlined.

B4.1.1 Applicable Regulations

The aircraft certification regulations that would apply to a scheduled air carrier CTR are the Interim Airworthiness Criteria for Powered-Lift Transport Category Aircraft, commonly referred to as Part XX (reference 2). This airworthiness standard will

remain in an interim status until the FAA and industry gain further experience in the design, development, and certification process for CTRs and other powered-lift aircraft. As is the general practice, an interim airworthiness criteria is not finalized and does not become a new part of the Federal Aviation Regulations (FAR) until an aircraft has been certificated using the criteria.

The airworthiness criteria specified in Part XX cover aircraft flight characteristics, structures, design and construction, propulsion system, equipment, and operating limitations. The requirements are intended to be general enough to cover a broad class of powered-lift aircraft including tiltrotor, tiltwing, lift-fan, and vectored thrust configurations. In design areas where the specifics of powered-lift concepts are sufficiently similar to airplane or rotorcraft standards, the Interim Criteria suggests that it would be appropriate to continue to use established standards resulting from aerospace industry and FAA experience. However, there may be no specific requirements for some systems, such as the drive system, because their designs may vary greatly between the different vehicle types. Instead, the Interim Criteria state that verification of the safety of the system must be accomplished by the applicant to the satisfaction of the certifying authority.

This requires the certifying authority to have familiarity and experience with the new technologies that may be used in the CTR. Indeed, this interim document acknowledges several areas that will require further study by the FAA in order to establish certification criteria. These areas include advanced flight control systems (e.g. fly-by-wire (FBW)), vertical control mechanisms (collective versus throttle), and low-airspeed handling qualities. The FAA has been working with National Aeronautics and Space Administration (NASA) to define criteria in these areas. This work should be continued by requiring the appropriate agency to develop a stable funding profile for research of this type.

B4.1.2 Failure Modes and Design Issues

Part of an aircraft basic design and certification review process is a thorough Failure Modes and Effects Analysis (FMEA). The failure modes of greatest concern for the tiltrotor are engine and drive system failures, conversion actuator failure, and FBW control system malfunctions. Tiltrotors also present design challenges with regard to flight loads and aeroelastic phenomena. The flight experience gained from the V-22 provides service data from a real operating environment that will be incorporated into a FMEA for the CTR. The following paragraphs describe several failure modes that are of concern and tiltrotor-unique design issues that must be addressed as part of the ongoing development of the airworthiness standards. These concerns and their possible solutions are illustrated with examples from the V-22 tiltrotor.

B4.1.2.1 Mechanical Systems

Engine failure is one of the greatest concerns in any aircraft. As described previously, a major safety feature for a single engine failure in a tiltrotor is an interconnect drive shaft (ICDS). During an one-engine-inoperative (OEI) situation, this shaft allows the equal transfer of power from the operative engine to both proprotors. In order to minimize diameter and weight, the V-22 ICDS is designed to carry a significant load only in such an OEI emergency situation (reference 9). At all other times, shaft torque is fed back to differential collective pitch on both proprotors to minimize the torque (loads) on the ICDS. This increases the life of the ICDS. With both engines operational, failure of the ICDS is not critical because it causes no loss of power or control.

Another safety concern is the pylon conversion actuator. The proprotors for a conventional CTR will be too long to avoid ground contact in an airplane-mode landing, and the proprotors must be reconverted at least partially to permit run-on landing without damage. Consequently, the conversion actuator must be highly reliable with built-in redundancies. For example, the V-22 conversion actuator assembly is powered by two hydraulic

motors with an electric motor backup mode (reference 10). This actuator design is such that a partial failure of the assembly still permits at least one-half nacelle conversion. On the V-22, the conversion actuator is controlled by the digital FBW control system which directs the position, speed, and synchronization of the two pylons.

An alternate proprotor configuration that would be capable of an airplane-mode landing is the variable diameter tiltrotor (VDTR). In this configuration, the proprotor blades are retracted in telescope fashion to reduce the proprotor diameter in airplane mode flight for better performance. The reduced proprotor diameter could allow the VDTR to land in airplane mode without proprotor damage. Of course, the requirement for actuators to effect the proprotor diameter change in a VDTR introduces additional complexities and failure modes that must be mitigated.

Another safety feature of the mechanical systems is a secondary lubrication system for the proprotor gearbox. If lubricating oil is lost due to a leaky seal or a cracked case, a secondary lubrication system minimizes the possibility that the transmission will fail before the aircraft can be landed. On the V-22, for example, the secondary lubrication system injects oil from a standby reservoir into the proprotor gearbox, allowing the aircraft to operate for 30 minutes in the event of a loss of oil pressure in the primary system. While this is a part of the V-22 for reasons of ballistic tolerance, it is recommended in the CTR as a safety feature.

B4.1.2.2 Flight Control System

In the advanced flight control systems being developed today, the pilot flies the aircraft through a computer. A "fly-through-computer" system provides stability augmentation and automated flight modes intended to reduce pilot workload. If the commands of the pilot are relayed electronically by the computer to actuators at the control surfaces, the system is called fly-by-wire (FBW). The two major domains of these advanced systems are software and hardware. Software covers the algorithms and rules that the computer uses to process pilot commands. Hardware covers the actuators, power supplies, feedback sensors, and the computer itself. The certification of FBW control systems is one of the areas requiring further definition in Part XX (reference 2). Software-based systems design is also an area where the FAA must develop expertise to provide oversight as cited by the GAO report (reference 7).

A FBW control system for a CTR is considered likely because it provides flexibility for the various control regimes required. Like the V-22, the CTR flight control system design will likely have no mechanical backup systems. During previous certification discussions regarding the V-22, the FAA has expressed concern over the reliability of flight control system and the thorough verification of the software (reference 11).

The reliability requirements of the V-22 flight control system were met through redundant electronic systems rather than through the use of mechanical systems. The V-22 has a triple redundant digital FBW flight control system (references 12 and 13). The system is further divided into a primary flight control system (PFCS) and an automatic flight control system (AFCS), each with its own set of triple redundant computers and sensors.

The V-22 PFCS has a dual fail-operate capability with dual processors. The system is designed for a mean time between failures (MTBF) of 10^7 flight hours. The CTR would be designed to higher civil requirement at 10^9 flight hours between failures. The V-22 PFCS uses a minimum amount of feedback (airspeed, nacelle angle, and roll rate) to minimize the possibility of uncommanded inputs to the flight control actuators caused by sensor failures. The system is intended to give the pilot as much direct control over the aircraft as possible.

The V-22 AFCS is single fail-operate and uses more feedback sensors with the goal of providing stabilization and improving handling qualities. This system is designed for 10,000 hour MTBF and is limited to 25 percent authority to prevent its failure from overriding the command of the pilot. The aircraft was also originally equipped with an ana-

log backup computer that provided a direct control method dissimilar to the digital flight control system. The flight control computers are powered by three electrical power sources, using separate permanent magnet electrical generators and batteries.

The V-22 flight control system uses a number of redundant actuators powered by three independent hydraulic systems to ensure high reliability. The hydraulic systems are designed so that loss of any one hydraulic system will not result in loss of aircraft control. The hydraulic system has failure detection and system reconfiguration capability. Actuator redundancy is provided by three actuators on the elevator, two actuators on each of the inboard and outboard flaperons, one each on the twin rudders, and three dual-piston actuators in each set of proprotor controls.

FBW control systems and digital computers greatly increase the options for flight deck automation. The impact of automation in the flight deck must be well understood, particularly with regard to this new type of aircraft. Possible confusion on the part of the pilot over automated mode selection, which has occurred on other aircraft (reference 14), must be avoided. Similar situations are known to have occurred in helicopters. Mode confusion can occur when an autopilot system is transitioning rapidly from one mode to another, e.g. from vertical climb mode, to altitude capture, to altitude hold mode. Tiltrotors are nonconventional aircraft with flying modes not found in fixed-wing aircraft or helicopters, such as the tiltrotor conversion mode. The pilot must be kept aware of the configuration and limitations of the CTR aircraft as well as the actions of the autopilot system.

Maintaining configuration awareness is more complicated in a tiltrotor, because it has two modes of flight control, i.e., aerodynamic control surfaces for fixed-wing flight and proprotor control for helicopter flight. As the aircraft transitions from one flight mode to another, one mode of control is phased out while the complementary mode is phased in. Because the flight computer manages control phasing to maintain a constant level of controllability, the pilot's stick no longer provides a direct indication of the position of the control surfaces. In addition, several automated functions may be used to reduce pilot workload. When these systems are operating, the pilot may not have direct control of some of the aircraft systems. FAA personnel must be knowledgeable about these software-intensive systems in order to certify that the design of the cockpit, information displays, and mode automation will not lead to pilot confusion.

B4.1.2.3 Structural Integrity

With its unique capabilities, a tiltrotor can perform maneuvers that conventional aircraft cannot. Some of these maneuvers can create extreme loads on the aircraft structures and the proprotor system. Designing for these structural loads presented a significant challenge in the case of the V-22. The designers met the requirements using two approaches. The first approach was to address structural loads through both the fixed and rotating flight control system. Collectively, the control law features designed to minimize loads are called structural loads limiting (SLL) (references 15 and 16). SLL represents an attempt to have the flight control system inhibit the ability of the pilot to overstress the aircraft through improper control inputs and also to limit fatigue damage to the aircraft.

The second approach in designing for structural loads was to meet extremely demanding strength and fatigue requirements for the V-22 airframe and dynamic components (reference 17). For the V-22, it was required that no component should yield (deform) due to a steady load caused by any maneuver. The airframe components are required to have a minimum structural fatigue life of 10,000 hours due to quasi-static (high-load, low-cycle) loadings. The fatigue life due to vibratory (high-cycle) loadings is required to be a minimum of 30,000 hours. Dynamic components such as the proprotor and drive system are also required to have at least a 30,000-hour structural fatigue life. In contrast, military helicopter structural design requirements normally specify a 5,000-hour fa-

tigue life, and sometimes less. The ruggedness associated with higher fatigue life is a direct contribution to safety.

Composites are used extensively in the V-22 because of their excellent fatigue properties and because they can be tailored to optimize the properties of a structure. In addition, they allow the more rugged design to achieve a smaller empty weight. The ability to tailor composites allows structures to meet demanding aeroelastic and vibration requirements. For these reasons and others, use of composites is considered likely on a CTR. However, composite materials are a developing technology with some unknowns regarding the effects of environmental degradation, damage propagation, and processing quality control. Furthermore, composite material has been cited as one of the technology areas in which FAA personnel require additional training so that they can adequately verify regulatory compliance. Much will be learned about composites from experiences on the V-22 and other programs, but FAA permanent staff specialists must monitor these developments in order to assist the certification personnel in defining requirements and verifying compliance.

B4.1.2.4 Crashworthy Design Features

Tiltrotors have several significant crashworthy design characteristics (reference 18). These include large mass relief, rollover stability, and reduced pitch and roll attitude upon impact. Mass relief refers to the placement of large mass items such as engines, gearboxes, and proprotors away from occupied areas. In tiltrotors, these mass items are located on the wing tips that can be designed to fail in a controlled manner. Shedding the wings and pylons during a crash reduces the aircraft mass by approximately 40 percent, further reducing the crash loads on the fuselage structure. Designing the wing and pylons to fail before the fuselage, therefore, is intended to prevent the collapse of the passenger compartment.

The attitude on impact of a tiltrotor in a controlled crash is expected to be nearly level, maximizing the energy absorbing function of the landing gear and fuselage structure. Tiltrotor wings have a beneficial effect on the roll impact attitude and help to right the aircraft and prevent rollover should the impact occur at a wing-low attitude. In the unlikely event of a rollover, the wing support structure and forward cabin bulkhead provide a strong rollover structure, preventing fuselage collapse.

Crashworthiness features specifically designed into the V-22 (figure B4.1.2.4-1) include energy absorbing features for the underfloor, crew seats, and landing gear. A crashworthy fuel system using self-sealing fuel lines and breakaway fittings is used. The fuselage is designed with antiplowing keel beams to prevent the nose from digging into

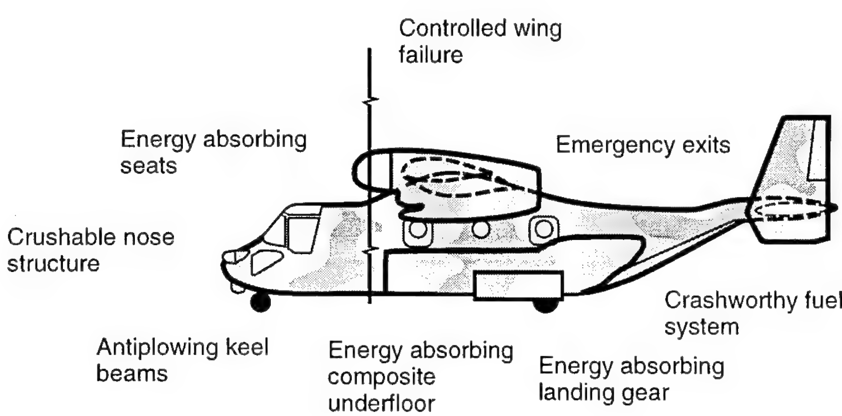

Figure B4.1.2.4-1 V-22 Crashworthy Design Features

soft ground on impact. Several emergency exits are located on both sides of the aircraft and are designed to be operated from both inside and outside. While none of these features are unique to a tiltrotor configuration, their development and proven benefits during years of military experience will certainly benefit any CTR.

B4.1.2.5 Flight Hazards

Flight hazards for aircraft, including icing, lightning strikes, and bird strikes, must be considered. Icing may be addressed by standard deicing and anti-icing techniques for the wing, proprotors, and engine air inlets. The tiltrotor has the added advantage of being able to convert to helicopter mode in the event of severe wing and tail icing due to deicing system failure. Lightning is of great concern in the presence of electronic FBW control systems and the potential use of composite structures. Design criteria are in place to address this issue as evidenced by various FBW and/or composite structure civil aircraft such as the recently-certified Boeing 777.

B4.1.3 Lessons Learned from XV-15 and V-22 Mishaps

Although a great deal of effort goes into designing aircraft systems to prevent failures, mishaps do occur. Lessons can be learned from mishaps involving tiltrotors, but several issues must be clarified. First, the flight history of tiltrotors is relatively brief and includes only experimental and military prototypes. There are no civil certificated or fully qualified military aircraft. Second, it should be noted that experimental aircraft such as the National Aeronautics and Space Administration (NASA)/Army/Bell XV-15, which carries only a flight crew and uses military ejection seats, are not designed to the same safety standards as FAA-certificated aircraft. Finally, none of the mishaps described in the following paragraphs was the direct result of tiltrotor technology. It is significant that the unique ability of the tiltrotor to tilt the proprotor system has not been the direct cause of any tiltrotor mishaps to date.

A review of the mishap histories of the V-22 and XV-15 tiltrotors shows that both configurations have survived several in-flight, single-engine failures or shutdowns. In each case, the tiltrotor ICDS transferred power to both proprotors as designed. The XV-15, flying well above helicopter speeds, also suffered a bird strike that seriously damaged a wing leading edge spar. The aircraft reconverted and landed without incident.

Three mishaps have occurred that resulted in the complete loss of a tiltrotor aircraft. The first involved the fifth prototype of the U.S. Navy/ Marine Corps V-22 (reference 19). The accident occurred on the initial flight of this specific aircraft. The aircraft was hovering just after lift off when it began to oscillate about its roll axis and had a tail-heavy appearance. As the pilots attempted to land, the left engine nacelle struck the ground. This forced the pilots to regain altitude and make a second attempt. During the second attempt, the left wing drooped in a larger roll, causing the left engine nacelle and proprotor to strike the ground. At this point, the nose dropped and the aircraft crashed.

The cause of the mishap was improper wiring of roll rate sensors in the primary flight control system. In this case, two of the three roll rate sensors were wired backwards, providing a destabilizing input to the roll axis. This manufacturing error resulted in pilot control inputs that were out of phase with the aircraft motion response. This was apparent from the roll oscillations experienced in hover. This incident with the fifth V-22 prototype showed that FBW control systems require a built-in test (BIT) to perform functional checks prior to each flight. Although the V-22 has a BIT to test the flight control system, it was not checked before the first flight. Another lesson learned is that the crashworthy design features of the V-22 worked. Both pilots walked away from the crash with only minor injuries.

The second incident involved the fourth V-22 prototype (reference 20). The sequence of events began as the nacelles were being rotated from airplane mode to helicopter mode in preparation

for landing. A leaky seal in the right engine nacelle of the prototype allowed combustible fluid to pool in the nacelle. During reconversion, the fluid was ingested into the engine causing an engine surge. The resulting flash fire damaged the composite ICDS which subsequently failed under load. Failure of the ICDS prevented OEI operation. The aircraft hit the water at a high rate of descent and nearly level attitude, killing all seven people on board.

As a result of this accident, the air inlet of the engine nacelle was redesigned to withstand higher overpressure loads, the forward firewall was modified, and drains were added to prevent fluids from pooling in the inlet. The composite ICDS segment within the forward nacelle was surrounded by a protective metal shroud and additional cooling air was introduced to provide a greater safety margin. This incident emphasizes the need for a very complete FMEA supporting the design of an ultra-reliable engine and drive system.

The third mishap was the crash of an XV-15 experimental tiltrotor (reference 21). The aircraft developed an accelerated right roll from a low altitude hover that could not be countered with a left cyclic control input. Both pilots walked away from the crash with minor injuries. A loose bolt in the proprotor control system was cited by the National Transportation Safety Board (NTSB) as the cause. Since the XV-15 was an experimental aircraft, it did not employ double retention of control system attachment hardware as would be required in an FAA-certificated aircraft.

The most important fact to be learned from these three mishaps is that **none was a direct result of the tiltrotor concept**. Each design or maintenance mistake could have also happened on either a turboprop aircraft or helicopter. Further, the specific causes of each mishap are not necessarily relevant to a CTR, because its design may vary significantly from either the V-22 or the XV-15. In general, though, the broad lessons concerning areas such as reliability, maintenance, and training are applicable to the design of a future CTR or any other advanced aircraft.

B4.1.4 Risk Reduction Tasks in Support of Initial CTR Certification

Certification requirements for this new type of aircraft must be based on a thorough understanding of the capabilities of a CTR and how design trade-offs can affect those capabilities. Engine-out performance and power-off landing requirements are two of the highest priority safety issues. The interim airworthiness criteria for powered-lift transport category aircraft requires that the aircraft must be capable of safely returning to the takeoff area or continuing the takeoff and climb-out under OEI conditions.

Such a capability represents a significant safety feature and should be required of any future scheduled air-carrier CTR. Depending on the proprotor design, tiltrotor OEI capability may require significant levels of engine reserve or contingency power. Safety can be enhanced with higher contingency power levels and by improving engine responsiveness to achieve these contingency power levels more rapidly. NASA and industry are currently investigating advanced contingency engine power technology and advanced variable diameter rotor technology to enable practical and efficient OEI capability for future CTRs.

In the event of an all-engines-inoperative situation, a CTR will have the capability to take advantage of lift contributions from both its proprotors and wing. In the V-22, these lift contributions from the proprotors and wings will be less than for similarly sized helicopters and turboprops due to the higher disk loading and higher wing loading of the tiltrotor.

Current data bases and validated analytical models are inadequate to predict tiltrotor autorotative capacity. These concerns can be overcome with wind tunnel and flight test validation of analytical models that predict autorotative capability and, if necessary, by incorporating design trade-offs that improve this capability. For example, larger proprotors with reduced disk loading and/or larger wings that are less heavily loaded could improve autorotative capability. Another design approach with potential to improve tiltrotor

autorotative capability is the variable diameter rotor. Consequently, power-off descent is an area that should be examined carefully to ensure that CTR aircraft are as operationally safe or safer than current transport aircraft. Engine-out and installed contingency power studies are recommended to augment the knowledge base necessary for certification.

With or without both engines operating, high reliability standards and backup mechanisms are required for the conversion actuators to ensure that the nacelles can be rotated toward helicopter mode for landing. Transmission reliability must also be considered. Due to the need for tilting gearboxes, interconnect shafting, and two proprotor speeds, tiltrotor transmissions are more complex than those found in turboprops and conventional helicopters. It is recommended that the FAA NRS personnel closely monitor the development of these systems so that their reliability can be assessed for certification purposes.

FBW flight control systems and automated flight decks are other issues that will require special attention during certification. Further work is required on flight deck human factors research. Recently, the FAA participated in an ongoing NASA Ames simulation study on cockpit display concepts for CTRs on steep instrument approaches (references 22 and 23). These studies looked at the use of flight directors, automated flap control, and semi-automated nacelle movement to reduce pilot workload on the steep instrument approach task. The continued support of FAA investigations with NASA in this area is highly recommended.

The goal should be to enhance FAA familiarity with the advances in these technologies in order to establish well-founded airworthiness criteria. Requirements for aircraft to meet certification standards do not guarantee safety if the basis for the standards are lacking or the certification evaluation is incomplete. Therefore, FAA involvement in tiltrotor flight safety studies and reviews must continue in order for the agency to be well versed in the technologies that it will later be asked to certify.

B4.2 Aircrew Training and Certification

Another certification issue that must be addressed is aircrew training and certification. The tiltrotor is not simply a helicopter that flies fast or an airplane that can hover. It is a powered-lift aircraft that has unique flight characteristics during its transition from rotor-borne flight to wing-borne flight and vice versa. The training issue for the CTR is likely to be a long-term issue of transition training since prospective CTR pilots are likely to hold either a fixed-wing or a helicopter certificate prior to tiltrotor training. The training syllabus may differ according to the background of the candidate. Training/transitioning and pilot qualifications must be addressed because tiltrotor operating characteristics encompass both helicopter and fixed-wing aircraft.

Training must deal with the configuration differences in flight deck layout and controls between CTR and either helicopter or fixed-wing aircraft. One example is the thrust control lever placement. In commercial fixed-wing aircraft, thrust control is provided by a throttle located on a center console. This places it to the right of the pilot and to the left of the copilot. A collective lever is used for thrust control in a helicopter. Both the pilot and copilot have a collective lever located on the left. Even more important is how this lever functions in the two aircraft types. In commercial fixed-wing aircraft, pushing a throttle away from the pilot adds power while pulling it toward the pilot decreases power. A helicopter collective works just the opposite. Pulling the collective toward the pilot adds power, while pushing it away from the pilot decreases power. The FAA has expressed concern that in time of stress, a pilot could become confused and mistakenly apply power when he or she intended to reduce power (reference 11). Such control input mistakes have occurred in simulations regardless of experience level of the pilot.

Since pilots tend to resort to their basic training techniques under stress, the challenge is to ensure that a CTR flight deck does not permit negative training transfer to cause errors in emergency situations. These concerns can best be addressed

through a significant simulation effort on CTR-unique human factors for flight deck design and pilot training. Such an effort is ongoing in the V-22 development program. Continued support of FAA/NASA studies is recommended. Since the flight decks of fixed-wing aircraft and helicopters have significant differences, the training program and the flight deck human factors research initiative must be closely linked.

Recently, the FAA published a notice of proposed rulemaking on pilot, instructor, and pilot school certification rules (reference 3). Of particular interest is the proposed addition of powered-lift aircraft as a new category for certification of private, commercial, and airline pilots and for flight instructor and ground instructor certificates. These changes are proposed in FAR 61, Certification: Pilots and Flight Instructors. As CTR aircraft and simulators are certificated and become more widely available, these proposed rules will be used in the certification of pilots and instructors.

B4.3 Operations Certification

Aside from the aircraft airworthiness (i.e., its physical characteristics), the most important factors determining aircraft safety are the applicable operating standards or regulations, the operating environment, and the mission to be performed. These factors affect the safety of both airplanes and helicopters and can be quantified by examining accident statistics.

Analysis of these data indicates that accident rates are reduced as more rigorous standards are applied and as the operating environment becomes more controlled. The following paragraphs discuss the existing standards that pertain to fixed-wing and helicopter operations.

B4.3.1 Effect on Accident Statistics

The Federal Aviation Regulations (FAR) that apply to operations certification are Part 91 (general aviation), Part 135 (commuter air taxi and commercial operators), and Part 121 (domestic air carriers). Part 91 regulations are the least restrictive. Part 135 requirements are more rigorous, and Part 121 regulations are the most stringent. Yet even within a single standard, such as Part 135, there can be operational variations such as scheduled service using established routes versus non-scheduled service to different destinations. General Aviation under Part 91 includes a great variety of operations or mission types, including personal use and training as well as commercial operations that are exempt from Part 135.

Past history indicates that comparable levels of safety can be achieved by both airplanes and helicopters when the same operating standards and/or regulations are applied and the aircraft perform the same mission, such as instrument flight rules (IFR) scheduled commuter service.

In order to make credible projections of CTR safety, helicopter and commuter turboprop accident data must be used appropriately. The database of Part 135 commuter operations for twin engine turboprops is well established in sources such as the NTSB database and references 25 and 26. Given the more limited use of helicopters in commuter operations, the results of the sampling and statistical methods used in the NTSB database are subject to large standard error values. For this reason, data compiled by the Helicopter Safety Advisory Conference (HSAC) are quite useful. HSAC is an organization of helicopter operators and oil companies that operate in the Gulf of Mexico formed to improve the safety of helicopter offshore operations. During the 1989 to 1994 time period, HSAC members flew 2.7 million hours and moved over 20 million passengers in 10 million takeoffs and landings. In 1994, they averaged 4,909 flights each day. Over this 6-year period, the aircraft fleet averaged 611 turbine helicopters (58 percent single engine and 42 percent twin engine). HSAC members operate under Parts 91 and 135. Such operations in a relatively controlled, professional environment provide a credible background for discussing CTR operational safety.

Figure B4.3.1-1 shows the accident rates for U.S.-registered airplanes and helicopters by type

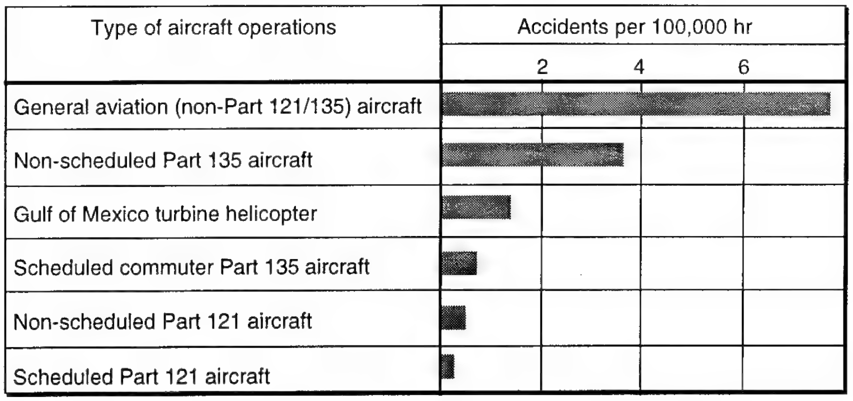

Figure B4.3.1-1 Aircraft Accident Rates (1989 - 1992)

of operation for the period 1989 to 1992 (reference 26). The data indicate that the least restricted type of operation, i.e., Part 91 - General Aviation, has the highest accident rate. As more rigorous operating standards and more controlled environments are applied, the accident rates decrease dramatically. It is clear that for similar types of operations (commuter Part 135 and Gulf of Mexico operations), the accident rates are similar (1.04 accidents per 100,000 hours flown for commuter Part 135 operations versus 1.6 accidents per 100,000 hours flown for Gulf of Mexico helicopter operations) when using comparable airworthy aircraft (turbine engine aircraft). Viewed from another perspective, this suggests that multi-engine turbine helicopters share a similar safety record with multi-engine turboprops. Consequently, CTR airworthiness can be expected to be comparable to these two aircraft types when used for similar mission applications and operated under similar standards and regulations.

B4.3.2 Operations Certification Standards for CTR Scheduled Service

Accident statistics have shown that compliance with stringent operating standards and a controlled operating environment can greatly enhance aircraft safety. However, it is also known that raising the certification requirements for operators can have a significant financial impact, especially on the smaller regional airlines (reference 27).

Since there are presently no operations certification criteria for CTRs in air carrier service, it is recommended that the FAA develop a standard that incorporates those requirements of the appropriate regulations that can significantly contribute to the safety of commercial CTR operations. This will require a thorough understanding of tiltrotor operational characteristics in order to define regulations that achieve the desired safety benefit. The intent of the applied regulations should be to balance the gains in safety against the cost of compliance.

By complying with suitable regulations, a CTR providing scheduled air carrier service can be expected to have an excellent safety record. The CTR is expected to embody a high level of airworthiness and to be operated by well qualified and trained crew members. While conducting scheduled service, the CTR operating environment will be strictly controlled with flights over well established routes. Furthermore, when the CTR enters service, it should benefit from safety enhancing technologies that are maturing rapidly. These technologies include the GPS, systems condition and usage monitoring, and newer flight operations and quality assurance (FOQA) techniques described in following sections of this report.

B5.0 Global Positioning System Based Traffic Control

Although navigation technology is part of the infrastructure required to support civil tiltrotor (CTR) operations, navigational accuracy affects the volume of cleared airspace necessary to meet current safety standards. Conventional ground-based navigational aids, such as the Instrument Landing System (ILS), provide line-of-sight, angular guidance. The system essentially emits a radio beam that guides the aircraft on approach. Since the radio beam spreads out over distance, a navigational aid must be located at each landing site to ensure the accuracy required for guidance close to obstacles such as buildings. With the vastly increased number of potential landing sites available to a CTR, it would probably be cost prohibitive to provide conventional navigation guidance sufficiently accurate to meet the required level of safety for navigation in the environments typically found in market-based vertiport sites.

The use of Global Positioning System (GPS) technology for horizontal and vertical navigation and instrument approach/departure procedures is expected to provide the level of navigational accuracy required to meet safety standards with less ground-based equipment and less cleared airspace than conventional navigational aids. Using GPS, CTR pilots will have an economical and highly effective method for conducting operations under instrument flight rules (IFR). By the end of this decade, the GPS Wide Area Augmentation System (WAAS) will enable Category 1 operations throughout North and South America. Even higher navigational accuracies (Categories 2 and 3) will be possible using a GPS Local Area Augmentation System (LAAS) transmitter near the landing site. The LAAS is expected to have the capability to transmit position corrections to aircraft conducting operations within a 30-mile radius, giving high accuracy and enhancing instrument approach safety. Both of these augmentation systems are known as differential GPS (DGPS).

Providing positive air traffic control (ATC) in a low-altitude environment poses a similar problem. Conventional radar-based methods for positive control of aircraft are also cost prohibitive. In metropolitan areas, a significant number of additional radar systems would be necessary to provide sufficient coverage due to building and terrain blockage. However, automatic dependent surveillance (ADS), based on GPS position data linked to an ATC facility by satellite or ground-based repeaters is expected to provide the required level of safety for a positive control environment. A satellite-based ADS system will soon provide a positive control environment for transoceanic flights that may allow traffic spacing to be reduced significantly while maintaining the required level of safety.

B6.0 System and Operations Trend Monitoring

Two additional benefits to aviation, made possible by advances in information processing technology, have the potential to contribute to the development and operational safety of a civil tiltrotor (CTR). These are systems condition and usage monitoring and flight operations quality assurance.

B6.1 System Condition and Usage Monitoring

Systems condition and usage monitoring systems (often referred to as health and usage monitoring systems (HUMS)) are currently being integrated into new aircraft and retrofitted into existing aircraft. Such systems monitor critical performance parameters and conduct diagnostics on aircraft subsystems such as the engine, the flight control system, and the transmission system (reference 28). Such technology can be used to monitor the structural integrity of critical airframe components. This condition and usage information is recorded for postflight analysis and can be used to extend component lives beyond traditional times between overhauls when supported by sufficient component life data.

The V-22 uses a vibration structural life and engine diagnostics (VSLED) monitoring system that will provide usage monitoring technology applicable to commercial use. This system performs rotor track and balance, interconnect drive shaft (ICDS) bearing and temperature monitoring, engine power assurance checks, engine monitoring, and structural monitoring of airframe, rotors, and controls. Monitoring systems can be developed that use diagnostic algorithms to detect faults before failures can occur. Using redundant coverage by different monitoring techniques can minimize the possibility of false alarms or missed detections. Also, because some vertiport facilities may provide nothing more than basic petroleum, oil, and lubrication (POL) servicing, systems conditioning and usage monitoring present a powerful maintenance tool that can augment the maintenance checks that are conducted at more extensive vertiport facilities.

B6.2 Flight Operations and Quality Assurance

Since crew error is cited as a factor in the majority of accidents, the aviation community has looked for ways to prevent such accidents. Over the last decade, approximately 40 foreign airlines have analyzed recorded flight data to detect latent errors in crew performance. U.S. authorities are beginning to acquire the means to do this. Such analysis allows the airlines to provide timely feedback to flight crews on recent performance and to identify training requirements, operating procedural changes, and trends for the entire airline. This process has been termed flight operations and quality assurance (FOQA).

Because FOQA is more easily implemented in new aircraft with digital databases and sophisticated monitoring systems, the CTR is a likely candidate to benefit from the potential increased crew performance and overall operating performance associated with this technology. CTR operators providing scheduled service should adopt a FOQA program (reference 29).

B7.0 Operations

B7.1 Ground Operations

One possible operational hazard on the ground side is rotorwash. As the vertical flow of rotorwash contacts the ground surface, the flow of the rotorwash turns horizontally and is also called outwash. The effect of outwash on personnel and equipment is a function of the outwash velocity and the height above the ground of the peak outwash velocity. These are primarily determined by the aircraft rotor radius, disk loading, and rotor height above the ground. Because tiltrotor outwash velocities are typically higher than those of a small helicopter, the potential for adverse effects on personnel, aircraft, and other equipment increases (references 30 and 31).

An additional concern is flying debris driven by the rotorwash. As stated in reference 32, "[a]irborne particles can pose great threats to ground personnel as well as the aircraft's structure... The biggest human limiting factor is the eyes. While protective eye wear can remedy potential danger, this solution may be unacceptable for civil airline and general aviation operations."

If the proprotors are kept turning during gate operations, proprotor thrust and the resulting downwash must be kept to near zero, or the high downwash velocities may necessitate the use of loading bridges similar to jetways used at airports to protect passengers boarding or exiting the aircraft. The need for loading bridges may be further driven by other tiltrotors maneuvering and taxiing in the vicinity of one that is boarding or unloading. Because of the horizontal tilt of the rotor blades when taxiing, tiltrotors, like helicopters, require higher power settings to taxi than a comparable turboprop. This creates higher air velocities. The greater land area available at an airport may enable these potential CTR concerns to be solved with operational procedures. Addressing this concern within the restricted land area at a vertiport is expected to require both operational procedures and vertiport design requirements.

The Navy is currently flight testing the rotorwash characteristics of the V-22 and results should be available by early 1996. These data should be useful in validating and refining existing CTR rotorwash analyses. However, it is not certain whether the Navy testing will collect the full range of data needed to support the analysis of civil vertiport scenarios.

B7.2 Air Operations

Wake vortices created by a tiltrotor in forward flight above 40 knots have the potential to impact operations of nearby light aircraft. Very little is known about this potential hazard. However, Federal Aviation Administration (FAA) flight research (references 29 and 33) indicates that large helicopters can generate strong wake vortices. Measurements have indicated that wake vortices can present a potential hazard to light aircraft flying well over a mile behind a heavy helicopter such as the CH-53E. Therefore, civil tiltrotor (CTR) wake vortices need to be investigated before the aircraft is introduced into operation.

B8.0 Conclusions

The Civil Tiltrotor Development Advisory Committee (CTRDAC) Environment and Safety Subcommittee arrived at the following safety conclusions after detailed review and full discussion of the available information:

1. Civil tiltrotor (CTR) aircraft can be developed and operated as safe elements of the national transportation system.

2. CTR aircraft share many safety attributes with both fixed-wing aircraft and helicopters. CTR aircraft also have safety features that are unique to the CTR design.

3. The interim powered-lift standards that apply to the type certification of CTR aircraft represent an adequate initial set of requirements for powered-lift aircraft. Particularly important is the requirement for scheduled air carrier CTRs to have significant OEI performance capability. However, some additional research is required to reduce the risk of failure or delay in the initial CTR certification activity.

4. Operations in compliance with rigorous certification standards in a controlled operating environment can greatly enhance aircraft safety. By complying with suitable regulations that demand the highest level of safety, a CTR providing scheduled air carrier service can be expected to have an excellent safety record.

5. There is a need to upgrade the capabilities of the Designated Engineering Representative (DER) and National Resource Specialist (NRS) programs to provide for the integrity of the certification process.

6. It is important that the flight characteristics and flight deck design of the CTR allow that direct transition training to CTR be possible for instrument-rated pilots from either the fixed-wing or helicopter communities.

7. The use of Global Positioning System (GPS) technology for navigation and differential GPS (DGPS) for instrument approach/departure procedures is expected to significantly enhance the safe instrument-flight operations of CTR.

8. System condition and usage monitoring technology and the use of a flight operations and quality assurance (FOQA) program can be expected to greatly enhance the safe operation of CTR, to reduce accidents, and to reduce the costs of maintenance and ground support.

9. The Federal Aviation Administration (FAA) Interim Airworthiness Standards for Transport Category Powered-Lift Aircraft will remain interim until an aircraft is certificated using these criteria. As with all new aircraft, CTR development will take place in an environment of closely monitored design and initial operations so that safety features will be an integral part of the aircraft that is finally presented to the FAA for certification.

B9.0 Recommendations

The following recommendations address the critical safety issues investigated by the Civil Tiltrotor Development Advisory Committee (CTR-DAC) Environment and Safety Subcommittee:

1. Research should be completed before the year 2003 to reduce the risks of failure or delay in the initial civil tiltrotor (CTR) certification program. At a minimum, this effort should include research in:

- Propulsion system (engine/proprotor) design for affordable, near instantaneous engine response to contingency power following a single engine failure.
- Designs for power-off landing capabilities, i.e., power-off control and landing capability to ensure operational safety that meets or exceeds current standards for transport aircraft, including rotorcraft.
- Fly-by-wire (FBW) technology research with an emphasis on failure modes analysis, certification criteria for reliability, and accurate low-airspeed measurement.
- System condition and usage monitoring technology research in areas peculiar to the CTR configuration.
- CTR human factors for flight deck design to include displays, a large field-of-view heads-up-display, common display symbology, controls and cockpit inceptors (i.e., power lever/throttle, side stick), emergency procedures, and situational awareness.
- CTR training requirements.
- Rotorwash and wake vortex measurements to assess the impact on ground operations and other aircraft for use in developing procedures to minimize/avoid that impact.

2. The Federal Aviation Administration (FAA) should review and revise current operations certification regulations that would be applicable to a CTR in scheduled air carrier service, ensuring that they provide the highest level of safety.

3. The FAA should continue to ensure rigor in the Designated Engineering Representative (DER)/ National Resource Specialist (NRS) safety, design, and certification processes by acquiring familiarity and experience with the new technologies that may be used in the CTR.

4. The certification of FBW control systems is one of the areas requiring further definition in Part XX, Interim Airworthiness Criteria for Powered-Lift Transport Category Aircraft. Software-based systems design is also an area where the FAA must develop expertise to provide appropriate oversight. The FAA should ensure that these needs are met during the ongoing application and refinement of these certification standards.

5. The air traffic control (ATC) system should be extended to include airspace infrastructure with instrument approaches/departures for CTR operations using Global Positioning System (GPS) and differential GPS (DGPS) and automatic dependent surveillance (ADS) where radar coverage is inadequate.

6. A flight operations and quality assurance (FOQA) program should be an integral part of any scheduled CTR transport operation.

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Civil Tiltrotor Development Advisory Committee

Report of the Environmental and Safety Subcommittee

Environmental Issues

CTRDAC Environment and Safety Subcommittee

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CTRDAC Environmental & Safety Subcommittee Report

Environmental Issues

CTRDAC Environmental & Safety Subcommittee Report
Environmental Issues

C1.0 Executive Summary

C1.1 Purpose

The Civil Tiltrotor Development Advisory Committee (CTRDAC) was established by the U.S. Department of Transportation as directed by Congress under the provisions of Public Law 102-581, Airport and Airway Safety, Capacity, Noise Improvement, and Intermodal Transportation Act of 1992. The Environment/Safety Subcommittee of the CTRDAC was tasked with identifying and investigating safety and environmental issues. This report examines the environmental considerations associated with the development and operation of the civil tiltrotor (CTR) and an enhanced infrastructure system to support the incorporation of tiltrotor technology into the national transportation system. The Subcommittee also considered safety issues related to the development and introduction of CTR. The results are contained in the previous section of this technical supplement.

C1.2 Background

The CTRDAC Environment and Safety Subcommittee was tasked with identifying and investigating environmental issues (reference 1), including an estimation of noise and emissions characteristics of CTR near landing sites, a review of en route noise characteristics, and land use and siting implications. The Subcommittee was also tasked with providing details on environmental characteristics to the Economics Subcommittee to help determine economic viability.

Tiltrotor technology has been successfully developed over the last three decades in a sustained cooperative effort by U.S. industry and Government. The XV-3 and XV-15 tiltrotor research aircraft programs contributed to the successful design of the military V-22 multi-mission tiltrotor now in final stages of engineering and manufacturing development (EMD). The V-22 is scheduled for production later in this decade.

V-22 production funds have been requested in the fiscal year 1996 budget for all deliveries beginning in 1999. The V-22 technology base also has potential application to the development of CTR. The CTRDAC has addressed a wide range of issues related to the potential development and implementation of CTR operation. In addition to environmental considerations, the CTRDAC Subcommittees have evaluated the issues related to CTR development, safety, infrastructure, and economics.

The CTRDAC is interested in CTR technology and, in particular, the public benefits that can be expected from this type of aircraft. In the future, it is anticipated that various sizes of CTRs may perform a wide variety of missions, including emergency medical service (EMS) and corporate/executive transportation. However, the analysis of the Economic Subcommittee has indicated that the largest public benefits from the CTR will probably result from a growth in aviation capacity and a reduction in airport delay and congestion. These benefits are expected with the introduction of CTR as a scheduled air carrier aircraft. When CTRDAC analyses required the consideration of specific aircraft characteristics, the vehicle used was the 40-passenger CTR2000 (figure C1.2-1).

Performance Summary	
Maximum vertical takeoff gross weight	43,150 lb at 2,000 feet/ISA +20 degrees C at sea level/standard day
Operating empty weight	28,623 lb
Design range	600 nm with full passenger load and IFR fuel reserves
Maximum cruise speed	350 knots at 25,000 ft
Best range airspeed	315 knots at 30,000 ft
Service ceiling	32,000 ft
Maximum range	>1,000 nm with IFR reserves
Installed Engine Characteristics	
Engine number and type	Two IHPTET turboshaft
Maximum takeoff rating	7,260 SHP/engine at sea level/standard
30 - second contingency rating	8,820 SHP/engine at sea level/standard 7,800 SHP/engine at 2,000 ft/ISA +20 degrees C
Physical Characteristics	
Rotor diameter (each)	36.3 ft
Fuselage length	62.4 ft
Height	23.6 ft
Width (rotors turning)	86.2 ft
Number of cockpit crew seats	2
Number of passenger seats	40 plus 1 attendant
Installed horsepower	7,260 shaft horsepower/engine at sea level/standard maximum static

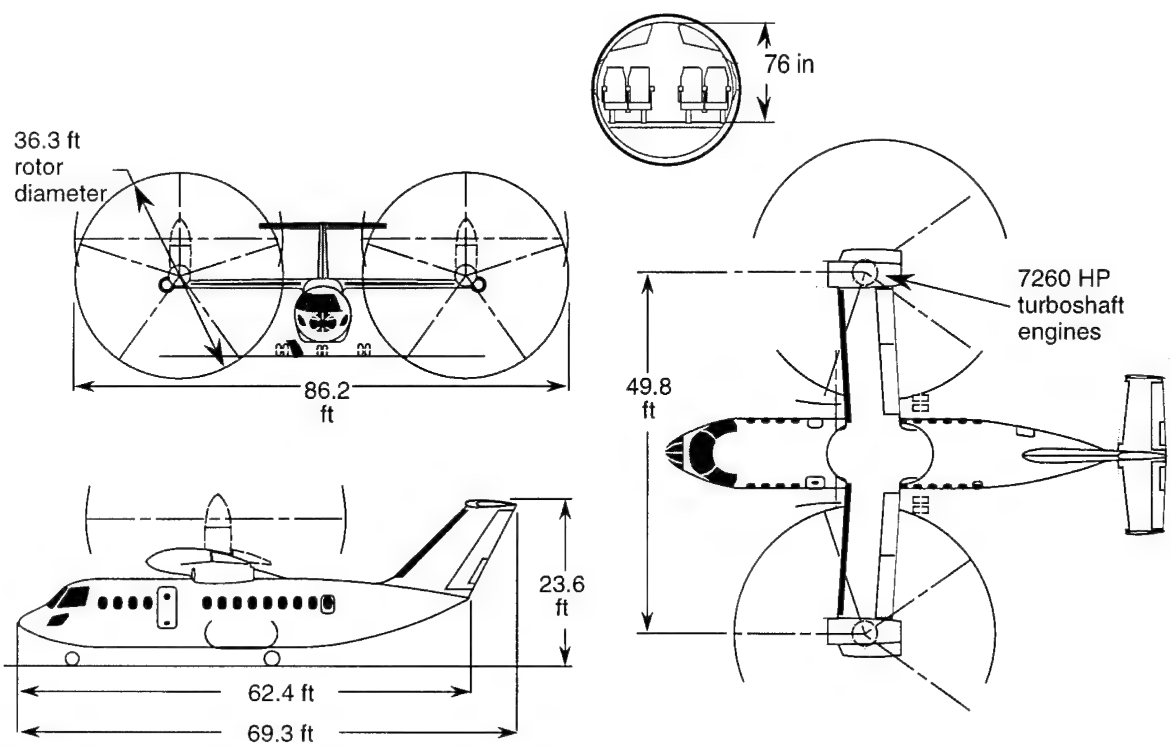


Figure C1.2-1 CTR2000 Characteristics

C1.3 Results in Brief

Gaining public acceptance for the introduction of CTR into the national transportation system is expected to be a formidable task requiring well-focused, cooperative efforts between industry and government.

Noise is a critical issue and poses the most severe obstacle to public acceptance of a system of vertiports. The requirement to locate vertiports in urban or suburban environments makes noise a critical issue in vertiport siting, just as it is in the siting of a conventional airport. Overcoming this obstacle to public acceptance will require the design of a new-generation rotor system along with the timely completion of focused research and the demonstration of results of noise reduction efforts.

Land-use/siting requirements will depend upon the degree of success achieved in noise reduction efforts. The challenge of achieving noise reduction is complicated by the lack of fully validated noise prediction methods and a lack of the ability to forecast community acceptance with an adequate level of confidence.

At this time, it is anticipated that integrating CTR into the national transportation system will result in an increase in the use of energy. A corresponding increase in emissions can also be expected. The level of these increases is unknown at this time but is expected to be small, and the increases may be mitigated by gains in total system efficiency resulting from the introduction of this new mode of transportation.

Providing the necessary technology and information base for the CTR by the year 2000 will require a sustained effort by industry and Government. Meeting the environmental challenge appears to be technically possible, although significant commitments by both industry and Government will be required to accomplish the necessary research and development.

C1.4 Concluding Remarks

The environmental feasibility of a viable CTR transportation system will depend on the ability of industry and government to meet the challenge of community acceptance. The critical determinant is noise and how it is controlled with aircraft design and operation as well as careful land-use planning. Current aircraft noise prediction procedures do not provide an adequate basis for estimating community response to helicopter and CTR noise or for related land-use planning and control. This is due to a lack of adequate data bases for frequent operation of heavy helicopters and CTR performance and noise definition. In contrast, the issues of energy use and emissions do not appear to be discriminators with respect to CTR environmental feasibility, although they may become more important issues for all modes of transportation in the future as restrictions on fossil fuel use and emissions increase.

C1.5 Key Recommendations

Key recommendations of the CTRDAC Environment and Safety Subcommittee relating to environmental issues are to:

- Augment existing CTR noise research.
- Develop better technical tools and metrics for calculating community noise levels and for predicting community response to CTR and helicopter operations.
- Conduct a program of flight demonstrations of CTR technology to assess community acceptance and environmental impacts.
- Include vertiports in local and metropolitan transportation system planning.
- Conduct analyses to improve the estimates of CTR emissions and the potential of CTR to add or subtract from air pollutants.
- Restore the Departments of Housing and Urban Development (HUD) and Veterans Affairs (VA) incentives for local compatible land-use planning in airport environments.

C2.0 Introduction

As a result of the growing maturity of tiltrotor technology fostered by the V-22 military development, attention is now shifting to the potential for civil applications. While tiltrotor research and technology development has evolved over the last four decades, the development of a compatible transportation infrastructure is only in its infancy. With proper planning and support, a new national transportation asset could emerge.

The key to the success of any civil tiltrotor (CTR) segment of the national transportation system is the development of an adequate infrastructure to fully complement what the available aircraft technology can produce. Without properly sited vertiports the CTR is not viable. Yet, the introduction of vertiports in urban localities, where the market potential exists, is believed to be a major challenge due to the probable environmental impact. Environmental issues rank high among the array of issues that must be addressed.

In order to address these CTR issues on a national scale, Congress included the establishment of the Civil Tiltrotor Development Advisory Committee (CTRDAC) under the provisions of Public Law 102-581, Airport and Airway Safety, Capacity, Noise Improvement, and Intermodal Transportation Act of 1992. The CTRDAC was chartered to evaluate the technical feasibility and economic viability of developing CTR and a national system of infrastructure as an integral part of the national transportation system.

Recognizing that system viability would be dependent upon the environmental compatibility of any CTR transportation system, the CTRDAC established a Subcommittee that was chartered to address the environmental issues. In a series of meetings and supporting activities since May 1994, the Environment/Safety Subcommittee has been evaluating these issues and formulating statements of findings and recommendations. This report highlights the key assessments, findings, conclusions, and recommendations related to a CTR transportation system and the environment.

C3.0 Background

C3.1 Aircraft Concept Evolution

Tiltrotors have been under development in the United States since the 1950s. The United Kingdom and Germany began work in the late 1930s and early 1940s, but these efforts did not reach full development. The basic design goal was to combine the hovering flight capability of a helicopter with the forward flight speed and efficiency of a fixed-wing aircraft. In 1958, the Bell XV-3 became the first tiltrotor to take off successfully like a helicopter and then convert to the airplane mode. The next generation tiltrotor, the XV-15, was first flown in 1977. The XV-15 has flown at speeds of up to 346 miles per hour. One of the two research aircraft is still in service. This program has been a joint effort of the National Aeronautics and Space Administration (NASA), Bell Helicopter, and the U.S. Army.

The current generation tiltrotor, the V-22 Osprey, is funded by the Department of Defense and is intended for use by the U.S. Marine Corps, U.S. Navy, and U.S. Air Force. The V-22 is being jointly developed by Bell Helicopter and Boeing Helicopters. The first flight was March 1989.

C3.2 CTR Operational Concepts

The 40-passenger CTR2000 is being considered as the basis for an air carrier CTR. Other sizes of air carrier CTRs might be developed to carry from 30 to 75 passengers. A European consortium, EUROFAR, is developing a civil tiltrotor (CTR) that would carry 30 passengers. U.S. and European manufacturers are also considering a general aviation CTR that would carry nine passengers.

The major potential CTR markets that have been identified are:

- Scheduled passenger service air transportation.
- Corporate/executive transportation.
- Resource development, especially support of offshore oil drilling.
- Cargo/package express.
- Public service, such as emergency medical service (EMS), rescue missions, and fire-fighting support.

The passenger market can be divided into three components: (1) high-density urban-area to urban-area markets, (2) feeder markets between a congested airport and smaller regional locations, and (3) transfer markets from a vertiport to a major airport to long-distance jet aircraft. All three applications are seen as potential means of reducing congestion and increasing capacity at major airports.

In the high-density markets, CTRs would compete with both jets and turboprops on the basis of shorter access/egress times resulting from the use of well located vertiports. In the feeder and transfer markets, CTRs would compete with turboprops by avoiding congested terminal airspace and runways.

Being able to implement these concepts will depend upon the economic viability of the technology and the environmental and safety considerations of locating vertiports in urban areas.

C3.3 Infrastructure

The additional infrastructure required to support a CTR transportation system has not yet been developed. This is in contrast to the highly developed state of tiltrotor technology. In order to assure community acceptance, urban vertiports are expected to pose challenges in public education, system design, and operation. Noise, access issues, intrusion on established communities, and

perceptions of safety are expected to be major concerns of those living and working near the site of any proposed vertiport.

It appears that regional feeder sites can be made available with modest development efforts. Establishing vertiports to serve low-density communities at new sites or at existing general aviation airports will constitute one segment of the feeder system. However, establishing the corresponding on-airport sites at congested airport hubs may require significant development to integrate the vertiport/airport airside and groundside facilities and systems.

In addition to the problem of community acceptance, vertiports require suitable terminal and en route airside infrastructure in order to support the introduction of all-weather scheduled CTR operations. This situation is now changing rapidly with the application of global positioning system (GPS) technology to enable practical CTR instrument flight operations.

C4.0 Environmental Considerations

The Subcommittee analyzed the significance of the environmental impact of civil tiltrotor (CTR) as well as the possible technological innovations that could mitigate this impact. Among the topics considered were: (1) the ability of the private and public sectors to accommodate Federal environmental objectives, (2) the potential impact of noise and air pollution on acceptance of the technology by passengers and local communities, and (3) the ability of the U.S. to meet its obligations under national and international laws.

In general, CTR environmental considerations relate to the same issues that must be addressed in any major transportation system program. The National Environmental Policy Act of 1969 is particularly relevant. Also applicable is Executive Order 12898, entitled "Environmental Justice", that states that minority and disadvantaged communities should not be burdened unduly with the environmental impact of development. The infrastructure envisioned for a CTR transportation system represents significant planning, design, and development challenges to achieve operational acceptance in markets in high-density urban environments.

C4.1 Noise

Noise is the most critical environmental issue for the scheduled commuter CTR. Industry is working to take all reasonable steps to make the CTR as quiet as practical. The key to reduced noise is the design of advanced rotor systems. Instead of the three-bladed rotor design of the V-22 that is a result of military shipboard compatibility requirements, the CTR is expected to have more blades operating at reduced tip speed. One step in the research process would be to perform a demonstration program with a tiltrotor modified to incorporate a four- or five-bladed rotor design. This aircraft would be used in a series of overflights and simulated approaches to demonstrate aircraft characteristics and to determine its acceptability to local communities.

Additional noise reduction technology research is being performed by National Aeronautics and Space Administration (NASA), although this research is being accomplished at a fairly slow pace due to funding limitations. The present pace of acoustic research is too slow to produce the results desired by the year 2005.

Subcommittee discussion on noise research included the need for reconsidering the applicability of "Schultz Curves" that measure the percent of people who are highly annoyed by certain noise levels (reference 2). These have been recently questioned by the National Research Council of Canada (reference 3). Current NASA research and development efforts include initial subjective testing of people's acceptance of noise with various spectrum signatures.

Neither the Federal Aviation Administration (FAA) nor the International Civil Aviation Organization (ICAO) has developed noise certification standards applicable to powered-lift aircraft. As with any new aircraft type, it is understood that such specific standards will not be developed in time to influence the design decisions that must be addressed in the development phase of CTR. However, there already exists a powerful requirement in paragraph 611 of the Federal Aviation Act (recently recodified as Title 49 USC section 44715) that mandates the incorporation of noise abatement technology into the design of all new aircraft type-certificated by the FAA.

Section 44715 specifically prohibits the FAA from issuing an original type certificate for any aircraft, regardless of whether noise certification

regulations already exist under Code of Federal Regulations, 14 CFR36, if the FAA finds that the manufacturer has not incorporated all technically practicable and economically reasonable noise abatement technologies appropriate for the aircraft design. This finding by the FAA must be made for the CTR prior to the issuance of its type certificate even if noise certification standards are already in existence for that aircraft type. Title 49 USC section 44715 requires the manufacturer to incorporate "all" technically and economically available noise abatement technologies as opposed to the implied requirement under 14 CFR Part 36 that the manufacturer need only incorporate those noise abatement technologies necessary to meet 14 CFR Part 36 noise limits.

The noise issue is directly linked to the infrastructure considerations related to vertiport design, siting, and flight operations procedures. Preliminary results of noise footprint predictions indicate that the smallest practical noise impact areas can be achieved by using segmented approaches. The CTR would approach the vertiport well above the normal fixed-wing approach angle and then transition to helicopter mode at a point close to the touchdown spot.

Noise associated with the CTR, and all aircraft operations, affects acreage around the actual vertiport. The area affected can be approximated for planning purposes by a noise metric that combines the frequency of flights, time of day, and noisiness of any given pattern of operations. Using projected estimates of both noise emissions and terminal area operating procedures for the CTR, the Subcommittee considered a "noise footprint" day-night sound level (DNL) contour pattern using a procedure similar to one used for many aircraft types and other transportation noise sources. These calculations considered a full-scale vertiport assuming 50 approaches and 50 departures daily. The sensitivity of the surrounding area to noise will depend on how the land is used. The size of the noise exposure contours are shown in figure C4.1-1. Figure C4.1-2 shows appropriate noise controls by land use based on Federal Aviation Regulation (FAR) Part

Noise Level	Contour Area (approximate)
DNL 75 dB	12 acres
DNL 70 dB	44 acres
DNL 65 dB	119 acres

Figure C4.1-1 CTR Noise Exposure Contours

For land within DNL 75 dB contour	Containment within vertiport boundary or use of compatibility controls is appropriate.
For land between DNL 75 dB and DNL 65 dB contours	Compatible land use, noise easements, and other compatibility controls are appropriate
For land between DNL 75 dB and DNL 70 dB contours	A narrow range of land uses are generally considered to be compatible. These include manufacturing and production uses, certain commercial uses, certain public uses, and certain recreational uses.
For land between DNL 70 dB and DNL 65 dB contours	A range of land uses are generally considered to be compatible. These include manufacturing and production uses, commercial uses, certain public uses and many recreational uses.
For land outside DNL 65 dB contour	A broad range of land uses are generally considered to be compatible. These include residential uses, public uses, commercial uses, manufacturing and production uses, and recreational uses.

Figure C4.1-2 Land-Use Noise Controls

150, Airport Noise Compatibility Planning, and various FAA advisory circulars. However, the final responsibility for determining the acceptable and permissible land uses and the relationship between specific noise contours rests with local authorities.

The Civil Tiltrotor Development Advisory Committee (CTRDAC) Infrastructure Subcommittee has determined that a typical ground-level vertiport facility will occupy 20 to 30 acres. A typical elevated vertiport facility will occupy 10 to 20 acres. Additional acreage around the vertiport

would have to be protected from incompatible land use. In a number of urban areas, there are sites where the adjacent areas are occupied by rivers, lakes, industrial parks, rail yards, freeways, flood plains, etc., and provide appropriate stable compatible land uses. Such sites are appropriate candidates for vertiports.

Private vertiports are expected to be smaller than public vertiports. Since the activity at a private vertiport is expected to be considerably less than a public vertiport, the noise exposure contours would be considerably smaller that the 12/44/119 acres discussed above.

C4.2 Vibration

Community reaction to building vibration and rattle produced by rotorcraft operations is not completely understood. Studies on human responses to helicopter flyover noise have shown a differentiation in subjective response as a function of the presence of vibration and rattle in structures and structural components such as window panes (reference 4). Subjective human response while indoors is strongly and negatively influenced when an outside source of noise induces noticeable vibration and rattle. Such vibrations and rattles can be induced in structures by the low-frequency acoustical emissions of helicopters.

The CTR may have the same potential for inducing structural vibrations as a helicopter during takeoff and landing. Consequently, the potential for adverse community reaction beyond any reaction predicted by current analytical methods for airplanes should be considered by the designers of the CTR as well as community and transportation planners. Aircraft designers may minimize the problem by altering the acoustic emissions to avoid the excitation frequencies that cause the structural response. Community and transportation planners may minimize the problem by locating vertiports and designing CTR approach and departure paths to avoid noise sensitive areas.

C4.3 Energy Consumption

As U.S. and international emissions regulations for civil aircraft become more stringent, the CTR will be required to meet these requirements. In addition, the CTR may be required to meet unique environmental regulatory regulations established by state or municipal governments.

Aircraft engine emissions include carbon dioxide, water, oxides of nitrogen, carbon monoxide, hydrocarbons, and sulfur dioxide. Aircraft carbon dioxide emissions can best be reduced by increasing the fuel efficiency of the aircraft. Major engine design changes will be required to reduce emissions of carbon dioxide and oxides of nitrogen by a significant factor.

While participating in NASA-supported programs, manufacturers have made a significant investment in the design tools and technology base needed for low emission engines. The NASA programs have a goal of reducing emissions of oxides of nitrogen by 70 percent. Incorporating these results into CTR engine development is expected to result in reductions of 40 to 50 percent from the levels produced by current conventional engines.

Comparisons of energy usage per passenger carried and distance traveled are crude. CTR energy efficiency is comparable to existing turboprop aircraft (figure C4.3-1). CTRs and turboprops both require about 30 percent more fuel per seat-mile than a state-of-the-art jet aircraft such as the 130-seat Boeing 737-300. Based on an initial fleet of 200 CTRs in a total air carrier fleet of over 6,600 aircraft and a regional commuter fleet of 6,200 aircraft, the total increase in energy consumption due to the introduction of the CTR is small.

The effects of CTR introduction on the total national transportation system effects are difficult to assess. It is possible, but not certain, that the introduction of CTRs will result in gains in total system efficiency. These potential gains would result from a reduction in air traffic delays and

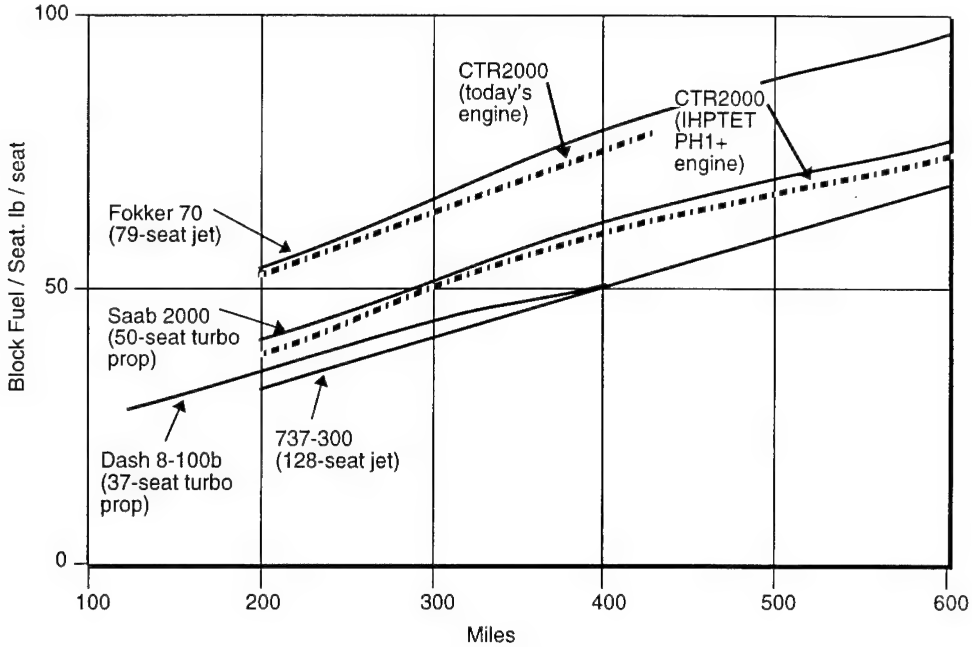


Figure C4.3-1. Comparison of Block Fuel Per Seat of CTR Versus Other Aircraft For Different Trip Lengths

energy use as passengers make shorter trips in automobiles to and from the vertiport compared to current trips to and from airports. Overall, the increase in energy use due to the introduction of a CTR transportation system is anticipated to be small, and not a discriminating factor with respect to the feasibility of the system.

C4.4 Emissions

The rate of engine emissions per pound of fuel burned varies with engine technology and with phase of flight. Compared to the engines on the Boeing 737, the CTR engine, which is envisioned to be an advanced low-emission variant of current engine technology, is expected to produce less oxides of nitrogen, but more hydrocarbons (HC) emissions per pound of fuel burned.

Again, total national transportation system effects are difficult to assess due to the difficulty of estimating the possible gains in total system efficiency mentioned above. The overall increase in emissions due to the introduction of a CTR transportation system is anticipated to be small, and not a discriminating factor with respect to feasibility of the system.

It should be noted, however, that two forces at work during the years when the CTR would be under development might cause either Federal or local government agencies to examine emissions more critically. National requirements for reducing CO_2 contributions to global warming, that may be called for before the end of the decade under the 1992 United Nations Convention on Climate, may cause a reexamination of all transportation modes that use fossil fuels. Metropolitan areas may also be forced to make hard choices on where their transportation investments are to be made to relieve traffic congestion and meet regional requirements under the Clean Air Act.

No CTR-unique engine emissions research is required. Ongoing research efforts to increase energy efficiency and reduce emissions will benefit CTR as well as conventional aircraft and should be continued.

C4.5 Land-Use and Siting Implications

As currently envisioned, the CTR2000 would operate into vertiports using a segmented approach. As a working guideline, it appears that a typical vertiport, anticipating up to 50 CTR approaches and 50 departures daily, should protect, through land-use restrictions, an area whose size is dependent on the nature of the adjacent land uses (figure C4.5-1).

Noise Level	Contour Area (approximate)
DNL 75 dB	12 acres
DNL 70 dB	44 acres
DNL 65 dB	119 acres

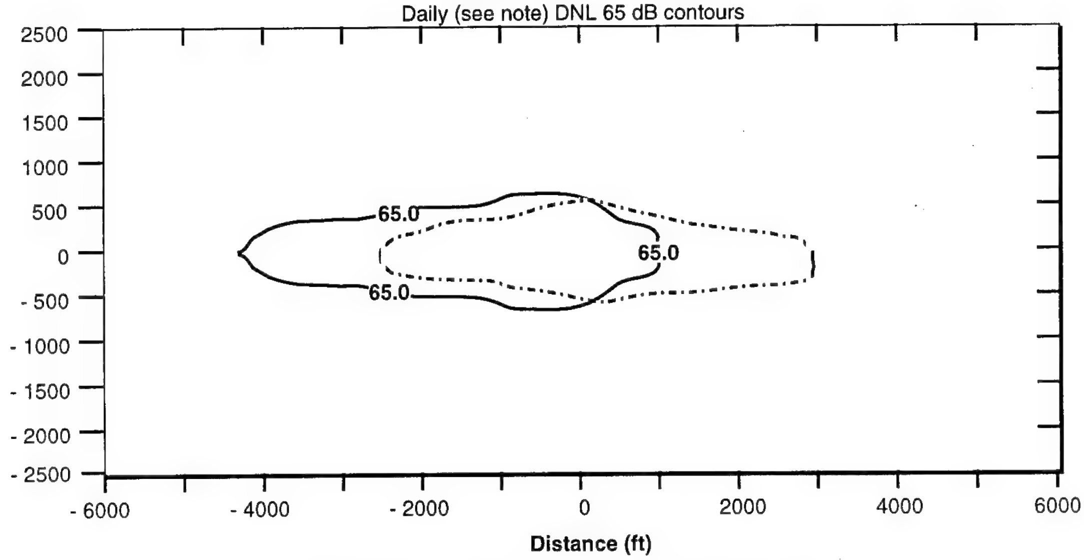
Figure C4.5-1 CTR Noise Exposure Contours

Figure C4.5-2 shows the shape of the 119-acre noise contour. The DNL 65 dB noise contour would enclose all of the actual vertiport facility of 10 to 30 acres.

Achieving acceptable noise levels within contours of these sizes will require sustained research in rotor design, flight noise data acquisition, noise prediction, and flight path management requirements. Figure C4.5-3 shows results of sensitivity analyses.

Until recently, the Departments of Housing and Urban Development (HUD) and Veterans Affairs (VA) had mortgage insurance programs in place that provided incentives for local compatible land-use planning in the vicinity of airports. As a result, neither HUD nor VA mortgage insurance was available for housing built in areas impacted

Segmented 9-degree approaches (single versus two directions)
50 daytime approaches and 50 daytime departures
5 rotor blades with 740 fps tip speed
Daily (see note) DNL 65 dB contours



One direction—DNL 65 contour level has 119.0 acres
Two directions—DNL 65 contour level has 138.4 acres

Note: Noise footprints are typically defined in terms of "yearly" DNL contours. This involves a calculation of the total yearly operations averaged over 365 days. However, since vertiports are expected to have significantly less operations on Saturdays and Sundays, the "daily" contour is slightly larger than the "yearly" contour.

Figure C4.5-2 CTR2000 DNL 65 dB Ground Contours

Size of the Various DNL Contours as a Function of Flight Operations

FAR Part 150:		DNL 75 dB	DNL 70 dB	DNL 65 dB	DNL 60 dB
		Industrial	Business	Residential*	
Daily number of approaches and departures	25	5 acres	21 acres	63 acres	178 acres
	50	**12 acres**	**44 acres**	**119 acres**	297 acres
	100	30 acres	79 acres	214 acres	480 acres

(CTR segmented 9-degree approaches, approach and departure on same heading)

* Vertiports are least likely to be developed in the vicinity of residential environments due to the environmental impact potential.

Size of the DNL 65 dB Contour as a Function of CTR External Noise Reductions and the Number of Flight Operations

CTR external noise reduction in comparison with the V-22:		Approximate reduction from V-22	
		9 dB	12 dB
Daily number of approaches and departures	25	63 acres	37 acres
	50	**119 acres**	63 acres
	100	214 acres	119 acres

Sensitivity to gross weight: Data are based on the CTR2000 taking off and landing at the maximum gross weight of 41,300 pounds. A typical landing weight is expected to be 36,600 pounds (based on fuel burn for a typical 200 nm leg at 60 percent load factor). This weight change is predicted to reduce the acreage inside the DNL 65 dB contour from 119 to 99 acres.

Sensitivity to rotor tip speed: Data are based on a CTR2000 hover rotor tip speed of 740 feet per second (fps). While this is considerably slower than the V-22 tip speed of 800 fps, CTR2000 hover rotor tip speeds in the range of 700 to 740 fps are being considered. If the CTR2000 is operated at lower tip speeds, the acreage inside the DNL 65 dB contour would be reduced from 119 acres to 110 acres and 100 acres at 720 and 700 fps tip speeds, respectively.

Figure C4.5-3 Results of Sensitivity Analyses

by airport noise. These programs helped to discourage incompatible development in the vicinity of airports. In the absence of these programs, investments in airports are at risk from encroachments that may prevent the facility from delivering the full benefits that would otherwise be possible.

C4.6 Community Acceptance

While community acceptance is vital to the success of the CTR as an element of the national transportation system, it is difficult to assess. A key to gaining community acceptance is to involve community leaders and planners early in the planning process of building vertiports as elements of local and regional transportation infrastructure. The challenge will be to address public concerns related to noise, safety, pollution, groundside congestion, and property values. A CTR demonstration will be needed to accomplish this.

Due to the lack of adequate data bases for frequent operation of heavy helicopters and CTR performance and noise definition, current aircraft noise prediction procedures do not provide an adequate basis for estimating community response to helicopter and CTR noise or for related land-use planning and control. The noise produced by a tiltrotor is not directly comparable to that produced by either fixed-wing aircraft or helicopters. Due to the unique flight characteristics and relatively large size of the tiltrotor, heightened community sensitivity to noise from CTR landings and takeoffs can be expected.

C5.0 Legislative and Regulatory Considerations

During the last two decades, numerous Federal laws and regulations addressing environmental impacts have been enacted. It is understood that all of these laws and regulations will be applicable to the proposed civil tiltrotor (CTR) system and to individual vertiports. However, no unique CTR-driven issues are expected to emerge.

Surface transportation legislation and aviation legislation may not be fully compatible and this may become an issue. In all likelihood, a CTR-based scheduled passenger service system would not be built without being part of a regional transportation plan. Facilities will not be constructed unless there is agreement by the metropolitan planning organizations (MPO) and unless each of the municipal and regional areas supports the project through the development of the plans. This type of planning and review would serve to legitimize the need for vertiports.

Due to the urban location of vertiports and the potential for their integration into an intermodal transportation system, the vertiport planning process should be included as an element of intermodal city transportation system planning. To this end, it is critical that vertiport planning be integrated into the Intermodal Surface Transportation Efficiency Act (ISTEA) and MPO processes.

Current Federal Aviation Administration (FAA) vertiport policy (references 5 and 6) limits additional planning studies and places restrictions on Airport Improvement Program (AIP) grants for tiltrotor and vertiport planning. Continuation of this policy will severely hamper the orderly introduction of CTR and vertiports into the national transportation system. In addition, revisions are in order for FAA Advisory Circular 150/5050-6, "Airport - Land-use Compatibility Planning" that discusses compatible land-use planning. This circular dated, December 30, 1977, was a valuable document, but apparently it has been canceled. The revision of this circular should specifically address vertiports and the tiltrotor.

The following are representative of the laws, regulations, and orders that were considered in reaching Subcommittee conclusions:

- Existing environmental protection laws and authorizing legislation.
- ISTEA of 1991, Clean Air Act Amendments of 1990 (CAAA), and FAA regulations.
- Local zoning/land-use regulations, System Planning: National Plan of Integrated Airport Systems (NPIAS), Airport Improvement Program (AIP).
- Executive Order 12898 on Environmental Justice.
- 1992 United Nations Convention on Climate.

C6.0 Conclusions

The Civil Tiltrotor Development Advisory Committee (CTRDAC) Environment and Safety Subcommittee arrived at the following conclusions concerning environmental issues after detailed review and full discussion of all available information:

1. Noise is the critical environmental determinant of public acceptance.
   - Noise abatement is key to achieving public acceptance.
   - Land-use planning and controls are essential to developing and operating viable vertiports.
   - Ongoing research to minimize civil tiltrotor (CTR) noise is promising but proceeding too slowly.

2. Methods and metrics currently used to assess aircraft noise around airports may not be adequate for land use planning and regulation of development with respect to vertiport operations in many communities.

3. Energy and emissions do not appear to be discriminators with respect to CTR environmental feasibility but may loom larger for all modes of transportation in the future as constraints on fossil fuel and emissions increase.

4. The prospect of a successful introduction of CTR service in urban areas will depend upon a realistic representation of the actual requirements for a vertiport, including the related noise-sensitive area to be protected.

C7.0 Recommendations

To address the critical environmental issues investigated, the Civil Tiltrotor Development Advisory Committee (CTRDAC) Environment and Safety recommends that:

1. Existing research to produce quieter civil tiltrotor (CTR) aircraft be augmented and accelerated.

2. Better technical tools and metrics be developed for calculating CTR noise levels and for predicting community response to CTR operations to guide planning for vertiports and the associated infrastructure system.

3. A program of flight demonstrations of CTR technology be conducted in and around selected cities and operational environments to assess community acceptance, environmental effects, and to gain operational experience.

4. Housing and Urban Development (HUD) and Veterans Administration (VA) mortgage insurance incentive programs for local compatible land-use planning in the vicinity of airports/vertiports be restored.

5. Analyses be undertaken to produce more accurate estimates of actual energy and emissions of CTR per seat mile and possible gains in total system efficiency under different scenarios of use and local traffic impact.

6. Local and regional transportation planning organizations be encouraged to include vertiports in local/regional transportation system planning:
   - Intermodal Surface Transportation Efficiency Act (ISTEA), Metropolitan Planning Organizations (MPO), etc.
   - National Environmental Policy Act (NEPA) (Environmental Impact Statement (EIS) requirements, etc.)

7. Local aviation interests should become active participants in ISTEA/MPO planning process.

8. Revise and reinstate Federal Aviation Administration (FAA) Advisory Circular (AC) 150/5050-6, "Airport - Land-use Compatibility Planning". This circular should specifically include relevance of vertiports and tiltrotors.

C8.0 References

1. "Civil Tiltrotor Development Advisory Committee Briefing Book", May 1994; section 2.1, Subcommittee Structure; section 4.1, Policy/National Issues.

2. "Synthesis of Social Surveys on Noise Annoyance", T.J. Schultz, Journal of Acoustics Society of America, Vol. 64, pages 377-405, 1978.

3. "On Dose Response Curves of Annoyance to Aircraft Noise", Bradley, John S.; Institute for Research in Construction, National Research Council of Canada; presented at the Internoise '94 Conference in Yokohama, Japan, August 29-31, 1994.

4. "The Role of Vibration and Rattle in Human Response to Helicopter Noise"; Schomer, Paul D.; Neathammer, Robert D.; US Army Corps of Engineers, Construction Engineering Research Laboratory, CERL Technical Report N-85/14, September 1995.

5. FAA Policy on Vertiport Studies, internal FAA memorandum dated Nov. 29, 1990.

6. Program Guidance Letter 91-2, internal FAA memorandum dated Feb. 8, 1991.

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Civil Tiltrotor Development Advisory Committee

Report of the Infrastructure Subcommittee

CTRDAC Infrastructure Subcommittee

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CTRDAC Infrastructure Subcommittee Report

CTRDAC Infrastructure Subcommittee Report

D1.0 Executive Summary

D1.1 Purpose

The Civil Tiltrotor Development Advisory Committee (CTRDAC) was established by the U.S. Department of Transportation (DOT) as directed by Congress under the provisions of Public Law 102-581, Airport and Airway Safety, Capacity, Noise Improvement, and Intermodal Transportation Act of 1992. The Infrastructure Subcommittee of the CTRDAC was tasked with identifying and investigating both ground and air infrastructure issues. This report examines ground and air infrastructure considerations associated with the development and operation of the civil tiltrotor (CTR) to support the incorporation of tiltrotor technology into the national transportation system. Economic, safety, environmental, and aircraft considerations were addressed by other CTRDAC subcommittees and are reported separately.

The CTRDAC is interested in CTR technology and, in particular, the public benefits that can be expected from this aircraft type. In the future, it is anticipated that various sizes of CTRs may perform a wide variety of missions such as emergency medical service (EMS), corporate/executive transportation, etc. However, the analysis of the Economic Subcommittee has indicated that the largest public benefits from the CTR will probably result from a growth in aviation capacity and a reduction in airport delay and congestion. These benefits are expected with the introduction of CTR as a scheduled air carrier aircraft. When CTRDAC analyses required the consideration of specific aircraft characteristics, the vehicle used is the 40-passenger CTR2000 (figure D1.1-1).

D1.2 Background

The Infrastructure Subcommittee of the CTRDAC was tasked (reference 1) with addressing the issues concerning both the ground infrastructure (vertiports) and the air infrastructure of the National Airspace System (NAS).

The issues involved in evaluating CTR ground infrastructure include: the feasibility of siting a network of vertiports in highly populated areas which is necessary for CTR economic viability; vertiport design and construction; ground-side integration of CTR at existing airports; the feasibility of financing the ground infrastructure through public and/or private means; and changes in regulations and standards.

The issues involved in evaluating CTR air infrastructure include: air traffic control (ATC); navigation and landing requirements; the impact of introducing CTR service on terminal and en route airspace capacity and productivity; changes necessary to adapt airspace navigation, surveillance and control procedures; development of special communications, navigation, and surveillance equipment/procedures for CTR operation; and changes in regulations and procedures.

The key infrastructure issues in evaluating the feasibility of CTR technology are community acceptance (including issues of noise, safety, and the willingness of the community to allow vertiports to be sited near passenger demand centers), overall infrastructure system design, identification of landing sites, and the ability to finance implementation.

Performance Summary	
Maximum vertical takeoff gross weight	43,150 lb at 2,000 feet/ISA +20 degrees C at sea level/standard day
Operating empty weight	28,623 lb
Design range	600 nm with full passenger load and IFR fuel reserves
Maximum cruise speed	350 knots at 25,000 ft
Best range airspeed	315 knots at 30,000 ft
Service ceiling	32,000 ft
Maximum range	>1,000 nm with IFR reserves
Installed Engine Characteristics	
Engine number and type	Two IHPTET turboshaft
Maximum takeoff rating	7,260 SHP/engine at sea level/standard
30 - second contingency rating	8,820 SHP/engine at sea level/standard 7,800 SHP/engine at 2,000 ft/ISA +20 degrees C
Physical Characteristics	
Rotor diameter (each)	36.3 ft
Fuselage length	62.4 ft
Height	23.6 ft
Width (rotors turning)	86.2 ft
Number of cockpit crew seats	2
Number of passenger seats	40 plus 1 attendant
Installed horsepower	7,260 shaft horsepower/engine at sea level/standard maximum static

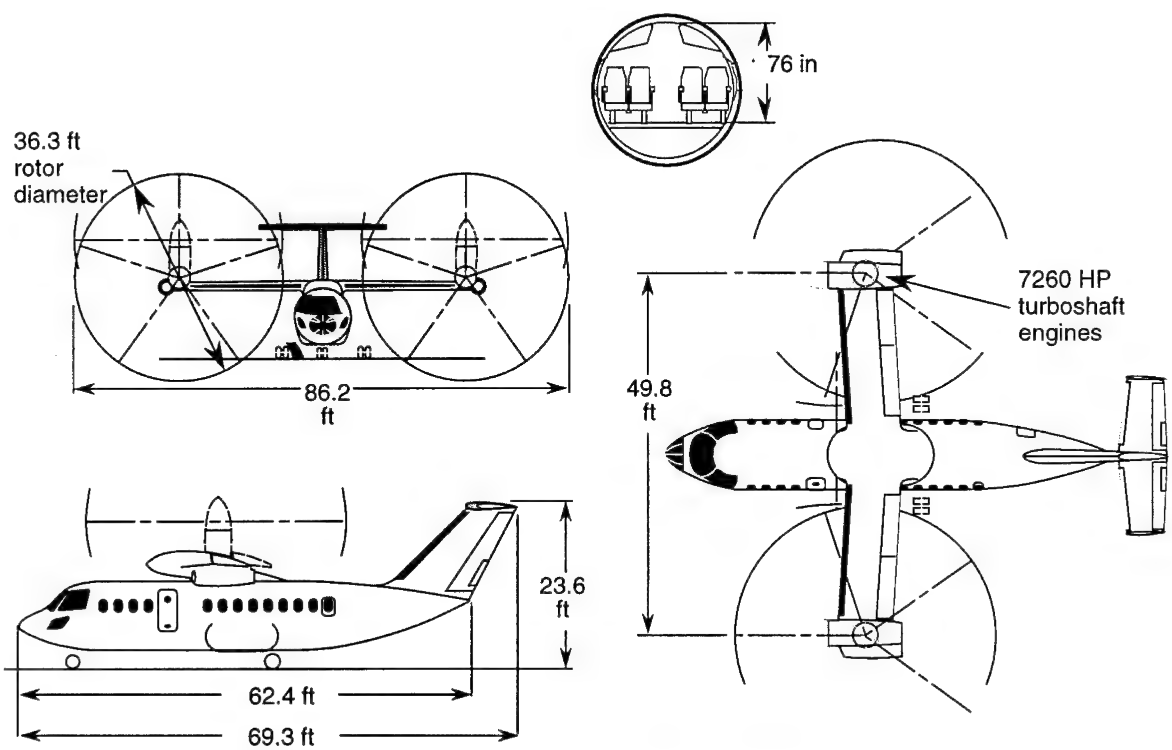


Figure D1.1-1 CTR2000 Characteristics

D1.3 Results in Brief

The economic viability of CTR will be dependent on the location of landing facilities in urban and suburban areas close to passenger demand centers. Thus, community acceptance will likely be the single most critical issue in developing the required infrastructure. Essential requirements for community acceptance are noise reduction or containment to minimize social/environmental impact and land requirements, public perception of safety, and public benefits.

To provide the capacity needed to handle the number of passengers required to make a scheduled air carrier system feasible, a typical ground-level vertiport will require approximately 20 to 30 acres. Elevated or multilevel facilities will require approximately 10 to 20 acres. In order to mitigate noise impacts, a vertiport should be located where the surrounding area has stable compatible land uses such as rivers, lakes, industrial parks, rail yards, freeways, flood plains, etc. Some regulation, such as zoning or restrictive easements, may be required to preserve the stability of this compatible land use pattern. The size of this surrounding area will be depend on the nature of the adjacent land use. Industrial and business land uses are normally compatible with noise levels below DNL 75 dB and DNL 70 dB respectively. Residential uses are normally compatible with noise levels below DNL 65 dB. The noise controur sizes are shown in figure D1.3-1.

Noise Level	Contour Area (approximate)
DNL 75 dB	12 acres
DNL 70 dB	44 acres
DNL 65 dB	119 acres

Figure D1.3-1 Noise Exposure Contours

Siting a vertiport will be a difficult undertaking in some cities. However, the Dallas Heliport/ Vertiport is an example of how it can be accomplished with minimum adverse impact while using a minimum amount of land.

From the standpoint of passenger demand and economic viability, the most important CTR commercial market would be downtown or suburban vertiport to downtown or suburban vertiport. A second market would involve flights from feeder airports to downtown or suburban vertiports. In a third market, CTR service would take the traveller from an urban/suburban area vertiport to a large airport for connections to conventional air services.

In a mature CTR system, vertiports are expected to be sophisticated facilities that provide the same types of passenger oriented services as hub airports. Both airside and ground side requirements will need specific design criteria to accomplish their functions safely while minimizing the environmental impact on the surrounding local community.

A draft of likely milestones for vertiport infrastructure development and construction has been prepared. It is based on the premise of creating a public/private partnership for coordination of a two-phased vertiport system development. A summary of the major milestones is shown in figure D1.3-2.

Vertiport development is subject to regulations at the Federal, state, and local levels that affect land use, zoning, financing, design, construction, and operation. Land-use compatibility and environmental regulations are of particular importance. The impact of a vertiport will depend on the vertiport location and function.

The Federal Aviation Administration (FAA) expects to be able to integrate CTR operations into the national airspace system (NAS) as it exists at the time CTR services are initiated. Although CTRs could be operated efficiently with minor changes in today's NAS, future NAS capabilities are anticipated which will be beneficial to all

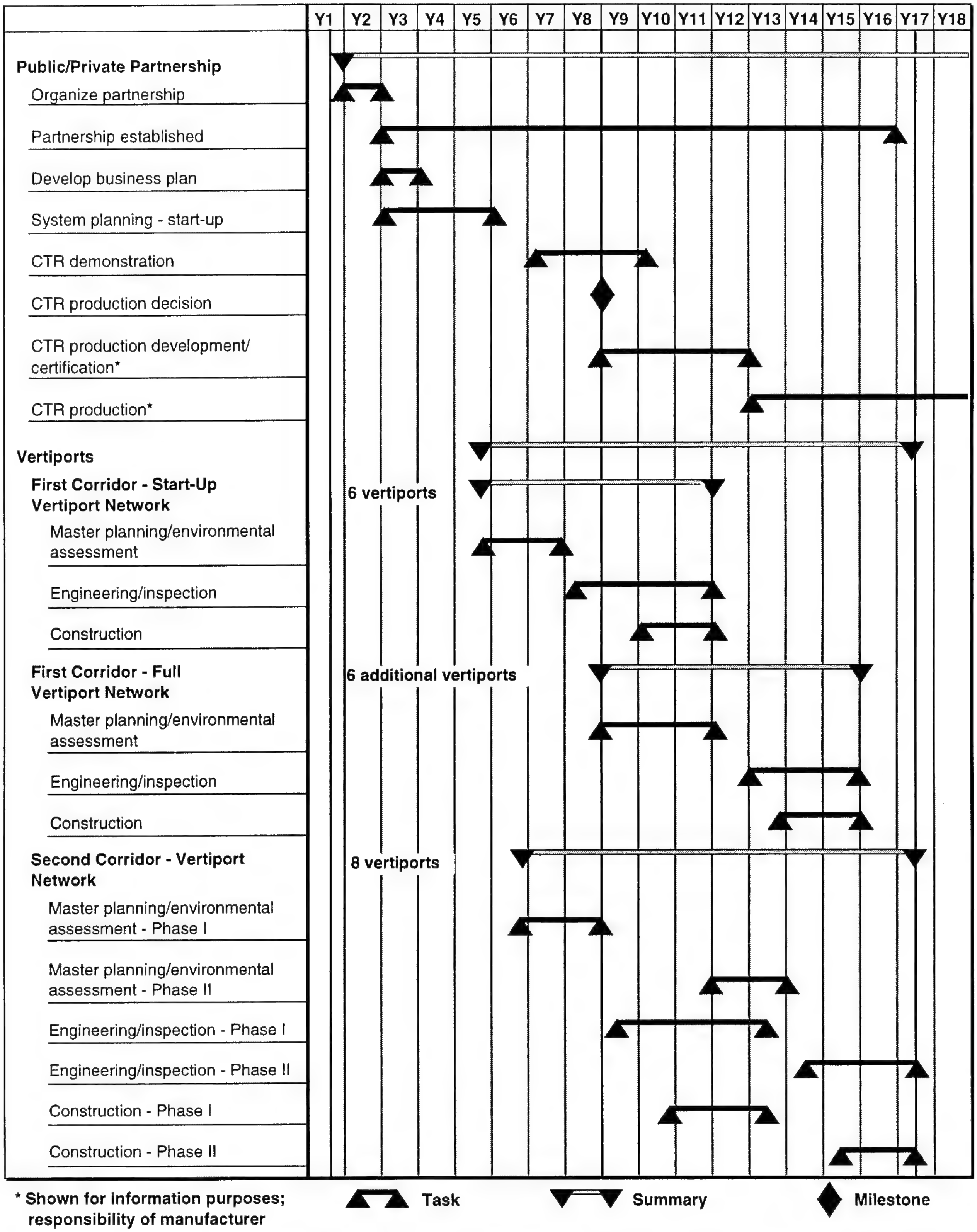
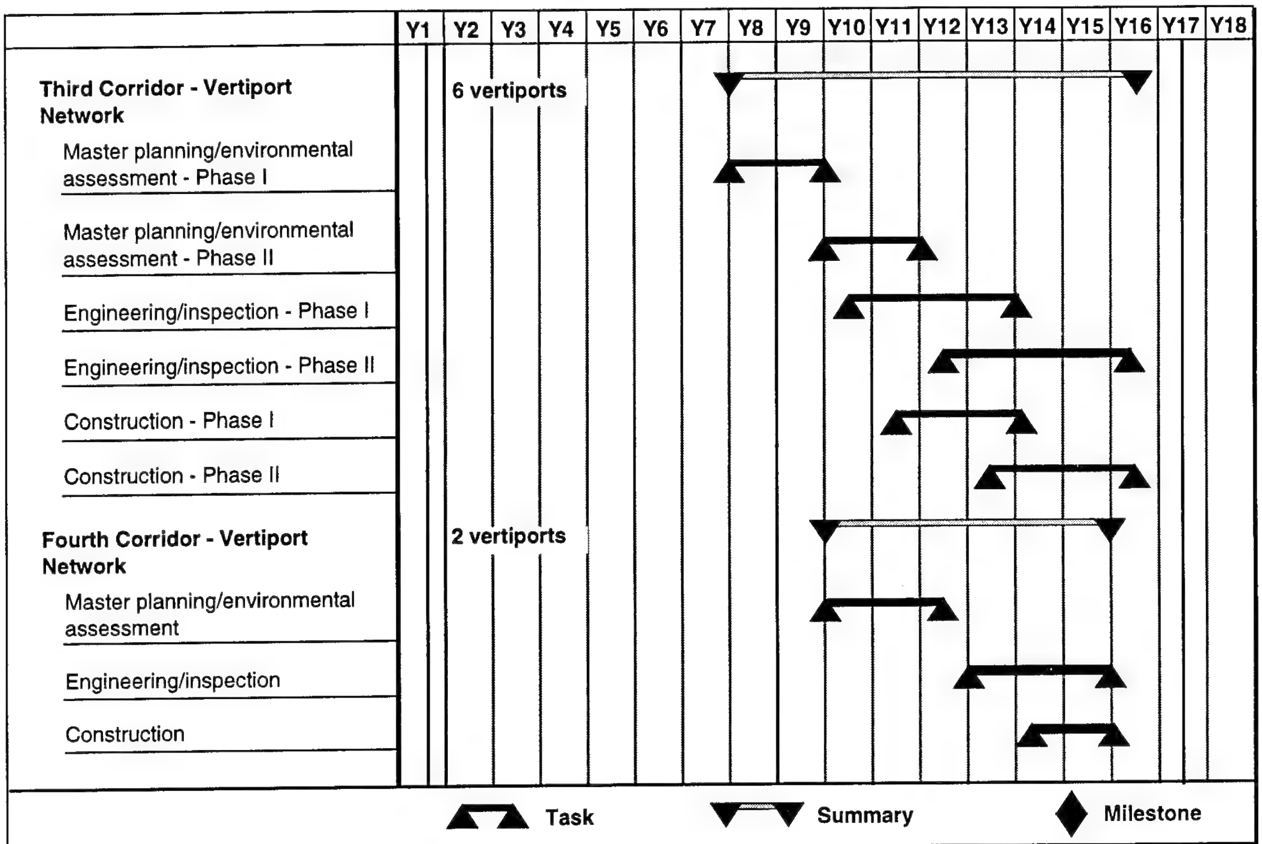


Figure D1.3-2 Notional Schedule - CTR Partnership and Infrastructure, Planning, and Development Milestone Summary (page 1 of 2)



COST (1,000)

Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9
200	900	1,300	700	1,900	3,600	6,900	8,480

Y10	Y11	Y12	Y13	Y14	Y15	Y16	Y17
41,175	109,545	121,900	195,265	147,365	28,450	4,150	3,750

Cost prior to CTR production decision	$ 15,700,000
Cost after CTR production decision	$ 660,080,000
Total partnership/infrastructure cost	$ 675,780,000

Figure D1.3-2 Notional Schedule - CTR Partnership and Infrastructure, Planning, and Development Milestone Summary (page 2 of 2)

aircraft including CTR. However, further research and development (R&D) is required in areas such as vertiport design criteria, air traffic procedures, aircraft separation standards, wake vortices, and rotorwash.

D1.4 Key Issues

The economic and operational feasibility of the CTR for scheduled passenger service depends on the ability to site vertiports in close proximity to passenger demand centers. This means that vertiports must be acceptable to urban and suburban communities. In many cities, obtaining vertiports sites in close proximity to passenger demand centers is expected to be a challenge. While it is no guarantee of community acceptance, CTR operations must be at acceptable noise levels, perceived as safe, and regarded as a community asset. In

some instances, a community must be convinced that a vertiport would be an appropriate use of scarce land resources.

The cost for implementing the first six landing facilities in the start-up Phase 1 CTR infrastructure is approximately \$67.5 million. The additional Phase 2 landing facilities (approximately 22 as suggested in figure D1.3-1) are estimated to cost \$599 million. Public/private partnership costs are estimated at approximately \$9.4 million for system planning and decision coordination. This total cost of \$676 million is for a program of approximately 10 years of planning, design, and construction. This is a significant cost. By comparison, however, a single instrument flight rules (IFR) runway at a major airport with associated lighting and navigation equipment can cost \$80 to \$500 million.

The typical public-use vertiport, sized to support short-haul commuter service, is expected to accommodate between 50,000 and 800,000 annual enplanements. (In calendar year 1993, the top 50 busiest airports each handled between 2.6 and 30 million annual enplanements.)

Analysis conducted for the CTRDAC Economic Subcommittee has indicated that there several options for financing vertiports. Under some of these options (see section D5), vertiports would be able to repay their capital and operations and maintenance (O&M) costs. However, all of these options are dependent on Congressional decisions on FAA budgetary matters currently under discussion.

In the current atmosphere of federal budget constraints and competition for those funds, Airport Improvement Program (AIP) discretionary grants may not be available for vertiport acquisition, construction, and implementation. However, formula-derived enplanement funds should be available on an annual basis. If this is the case, the primary source of initial vertiport funding would be private investment.

D1.5 Key Recommendations

In order for government and industry to make the many decisions that would be necessary to proceed, the CTRDAC Infrastructure Subcommittee makes the following key recommendations:

1. A public/private partnership of Federal, state, regional, local governments, and transportation authorities, plus applicable industry and private interests should be established to evaluate in detail the economic, political, and environmental feasibility of a system of CTR landing facilities. An initial task should focus on a network of specific locations in an area such as the Northeast Corridor.

2. A more detailed analysis should be conducted to determine the availability and financial feasibility of specific vertiport sites in a network. Such studies should be conducted jointly with responsible parties from the various states and metropolitan areas.

3. Industry should continue to make every effort to enhance CTR safety, passenger comfort, and minimize CTR internal and external noise.

4. Vertiports should be considered in urban/community development plans, as part of the comprehensive, continuing, and collaborative process.

5. The public/private partnership should conduct a flight demonstration program in selected cities of the flight characteristics and environmental impact of a representative CTR. Such a demonstration is essential in evaluating whether the public and potential CTR operators will accept and support this new technology.

6. The FAA needs to develop standard guidelines for terminal route design, for implementing and designing airspace at vertiports, and for assessing impacts on local and regional airspace.

7. The FAA needs to develop terminal instrument procedures (TERPS) to support CTR operations at vertiports. This should address Category 2 and Category 3 operations as well as missed-approach procedures.

D2.0 Introduction

The continuing increase in the number of congested existing airports and the difficulty in siting new air-carrier airports has led to the search for transportation alternatives to alleviate congestion and delay. Advances in tiltrotor technology indicate that a short-haul civil tiltrotor (CTR) transportation network may be an attractive alternative. Because the CTR can operate from off-airport facilities or vertiports, it could provide transportation services without using additional scarce runway capacity.

The infrastructure necessary to support a short-haul CTR transportation network is comprised of both ground and air system elements. Vertiports are the main component of the ground infrastructure. The planning, design, and implementation of vertiports encompasses such issues as community acceptance, site selection, compatible land use planning, facility design, construction, operating regulations and procedures, intermodal transportation, and financing. Air infrastructure encompasses the air traffic system, terminal instrument procedures (TERPS), en route and terminal air traffic control (ATC) procedures, routes, and the equipment required to support the operation of a CTR network.

D2.1 Community Acceptance

D2.1.1 Community Acceptance Issues

Since the economic viability of CTR will be dependent on the location of landing facilities in urban and suburban areas, community acceptance will likely be the single most critical issue in developing the required infrastructure. While there are no guarantees for community acceptance, it is essential that noise be reduced or contained to minimize social/environmental impact and land requirements. It is also essential that the public perceive that CTRs are safe and that vertiport sites are selected wisely. In some cases, a community must also be convinced that a vertiport would be an appropriate use of scarce land resources.

While community participation will not ensure community acceptance, community participation must be incorporated in the earliest stages of vertiport planning. The public should be kept advised of the requirements for, and benefits of, a CTR system as part of a general awareness of the need for a systematic approach to planning for public transportation. Public reaction to CTR noise, safety, and flight operations will drive system planning and design.

Although it is recognized that the noise levels associated with CTR operations are minimal during airplane-mode flight, external noise levels are considerably higher during landing and takeoff while the aircraft is in hover-mode in close proximity to the vertiport.

Details of efforts to predict and evaluate CTR noise are included in the Environment and Safety Subcommittee report on environmental issues. Research and development (R&D) efforts are underway to reduce CTR noise levels during approach profiles to minimize the noise footprint of the aircraft. Details of safety concerns are included in the Environment and Safety Subcommittee report on safety issues.

Public acceptance of CTR for scheduled passenger service in urban or suburban settings may depend heavily on the degree to which the aircraft is perceived as a community asset, rather than a liability.

D2.1.2 Vertiport Siting

To investigate the key issue of vertiport siting, airport authorities of New York, Boston, and Washington, D.C., were solicited for their opinions on

the potential of CTR transportation service and vertiport development. A summary of written inputs from these authorities is presented below. Section D10.0 contains the full text.

The Port Authority of New York and New Jersey (PANYNJ) has performed several vertiport feasibility studies (references 2-4). While it is difficult to build any large facility in Manhattan, the PANYNJ has indicated continued interest in the CTR to relieve airport congestion. The PANYNJ has defined the conditions under which they would proceed with vertiport development. These conditions include: a substantial passenger market that cannot be served efficiently at existing airports/heliports; the availability of a CTR design that is proven safe, efficient, and environmentally acceptable; and private sector investment in CTR aircraft by reputable air carriers.

Washington, D.C., has shown some interest through heliport and vertiport feasibility studies (reference 5). However, the Metropolitan Washington Airports Authority cites problems in the logistics of system development and a lack of support from the District government. Vertiport development in Washington, D.C., is also constrained by security-related restrictions on airspace in the prohibited area around the Capitol and the White House, commonly referred to as P-56. Other constraints include the lack of downtown land at the determined center of demand, loss of tax revenue from land transferred from business use to airport use in a high demand area, opposition from existing building owners and local government to putting a facility on a rooftop, and the cost of construction. The Authority cited the possible use of National Airport as a CTR landing site for downtown Washington, D.C., with Dulles Airport used as a site for Northern Virginia, and Montgomery County Airpark used as a site in the Maryland suburbs.

Boston has also shown interest through a multiple-phase vertiport feasibility study (references 6 through 8). However, the Massachusetts Port Authority has not provided an official written opinion to the Civil Tiltrotor Development Advisory Committee (CTRDAC).

In summary, airport authorities in the Northeast Corridor recognize the difficulties involved in building a major facility, such as a vertiport, near passenger demand centers. With airports, similar concerns have required that new facilities be located many miles from city centers. Since vertiports will affect considerably less land than a major airport, it may be possible to locate them in industrial and business areas close to passenger demand centers. However, there is considerable uncertainty involved. Based on CTRDAC analyses, the CTR/vertiport concept shows some promise but it is premature to expect communities to make any commitments.

It is anticipated that a demonstration of the flight and environmental characteristics of an actual CTR in selected cities would aid in evaluating whether the public will accept and support this new technology.

D2.2 CTR Commercial Markets

The unique operating characteristics of the CTR allow it to be operated in new and distinctive ways that may provide an scheduled passenger service alternative to certain existing fixed-wing air carriers. In order to evaluate the CTR as a potential transportation system, the mechanics of how CTR systems could viably operate must be understood. CTR economic feasibility depends upon the location of vertiports near passenger demand centers. In many cities, it may be difficult to locate vertiports at sites that are close to demand centers.

Operational system concepts using CTR aircraft have been studied by numerous groups. Three commercial markets have been identified as supporting efficient and economical systems for CTR scheduled passenger transportation networks (see Economic Subcommittee report). These commercial markets are shown in figure D2.2-1 and described in the following sections.

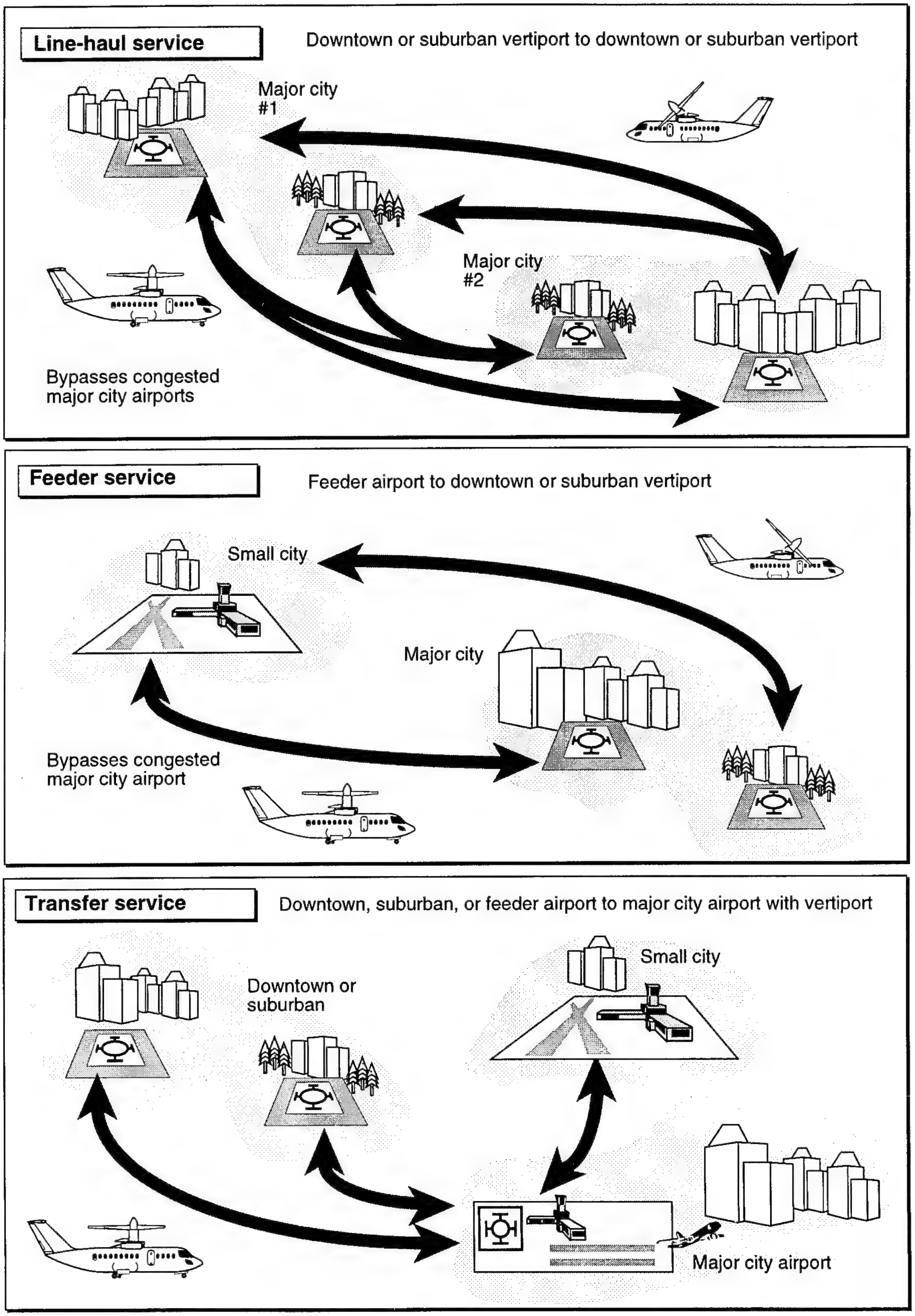


Figure D2.2-1 CTR Commercial Markets

D2.2.1 Downtown/Suburban Vertiport to Downtown/Suburban Vertiport

In this market, the CTR could provide alternative transportation from an urban/suburban vertiport in one city to an urban/suburban vertiport in another city. For example, in the Washington, D.C., metropolitan area, a vertiport at an active suburban location could be an origin/destination for a midtown Manhattan vertiport origin/destination. These types of travel markets may provide strong flows of both business and pleasure travelers. Most airports in these markets are already congested both in the air (Federal Aviation Administration (FAA) slot controls) as well as on the ground access routes, particularly during morning and afternoon peak traffic periods. Therefore, use of this urban/suburban area to urban/suburban area structure as part of a CTR transportation system is expected to save trip time for travelers.

In analyses conducted for the CTRDAC Economics Subcommittee, this market is estimated at 5.9 million passenger trips in 2010 in the four major corridors studied. This is the most important CTR market and site selection is critical.

D2.2.2 Feeder Airport to Downtown/ Suburban Vertiport

In this second market, the CTR could connect small city airports to urban/suburban areas by providing scheduled passenger service transportation to downtown or suburban vertiports from feeder airports located between 200 and 500 miles away. An example is a flight from the Syracuse, New York airport to a midtown Manhattan vertiport.

The airport CTR facilities in this structure would not necessarily have to be separate vertiports because a CTR may use airport facilities with little or no changes. Better CTR passenger services might be provided by constructing an airport gate specifically tailored to match CTR aircraft characteristics. However, at many small airports, airport changes might not be necessary, particularly for start-up operations. This type of operation is anticipated to save time over the current fixed-wing service that must operate from airport to airport. Business travelers wanting to minimize trip travel time and ground transportation costs are likely to be prime users of this type of service.

At an uncongested feeder airport, CTRs would operate on an existing runway and the construction of a separate, on-airport vertiport would not be required. When CTRs operate at large, congested airports, the development of a separate vertiport would be advantageous. This would eliminate the need for CTRs to use existing runways, thereby avoiding the associated delay and increasing the airport's capacity.

In analyses conducted for the CTRDAC Economics Subcommittee, this market is estimated at 4.5 million passenger trips in 2010 in the four major corridors studied. This is the second most important CTR market.

D2.2.3 Downtown/Suburban Vertiport to Collocated Airport Vertiport - Transfer Passengers

In this third market, CTRs could operate from downtown or suburban vertiports to collocated airport vertiports. This CTR service would take the traveller from an urban/suburban area vertiport to a large airport for connections to conventional air services.

For example, consider CTR service from a vertiport in the Washington, D.C. suburbs to a vertiport at JFK International Airport for a connection to a flight to Budapest or some other location where a direct flight is not available at the Washington, D.C., area airports. In this scenario, the creative operator would use the CTR to provide a competitive edge by saving travel time and maximizing passenger volume through a space- and volume-limited JFK airport facility. The goal would be to reduce pressure on the limited number of takeoff/landing slots, gate facilities, and precision approach airspace.

In analyses conducted for the CTRDAC Economics Subcommittee, this market is estimated at 5.2 million passenger trips in 2010 in the four

major corridors studied. However, this market is heavily dependent on a number of variables, including the airport hub and spoke system in use at that time, the degree of cooperation achieved between CTR operators and major airlines, and the competitive response of major airlines. This market is characterized by the greatest uncertainty.

D2.3 Financial Considerations

This section describes a variety of financial alternatives, many of which are traditional methods of financing airport improvements. From a practical standpoint, some of these alternatives may not be available. In order to obtain funding, it will be crucial to convince a variety of involved organizations of the feasibility, viability, and benefits of a CTR system. Financing feasibility will depend on assessment of the facilities needed, the availability of government grant funding, the availability of other financing, the timing of the project, and market conditions. Various methods of financing may be used in combination. As described below, it is expected that the bulk of the financing for the construction of facilities will have to come from private investment.

D2.3.1 Federal Airport Assistance

To promote a safe and efficient nationwide system of public-use airports, the Federal Government has made grants to state and local governments since 1946. Initially, the Federal Aid Airport Program drew funding from the general fund of the U.S. Treasury.

In 1970, the Airport and Airway Trust Fund was established based on aviation user taxes. Grants were made from the trust fund under the Planning Grant Program and the Airport Development Aid Program. The two programs were combined in 1982 under the current Airport Improvement Program (AIP). During fiscal year 1995, AIP funding totaling $1.45 billion was appropriated from the trust fund. However, as with all Federal funding, the future availability of AIP funding is uncertain and subject to competition.

During fiscal years 1989 through 1993, vertiport system analyses were completed by 16 metropolitan planning organizations (MPO) and states under the AIP at a cost of approximately $3 million. These were conceptual studies and no vertiport master planning has been undertaken to date using AIP funding or passenger facility charges (PFC). AIP-funded planning of airport, heliport, and vertiport infrastructure may take the form of a system plan for a network of facilities within metropolitan areas or states, or a master plan for an individual facility.

Recognizing that the manufacturers have not yet made a commitment to build a 40-passenger CTR, the FAA has indicated that, under current policy, it will approve new AIP or PFC applications for stand-alone vertiport planning only if the project would add significantly to information derived from the initial round of vertiport studies. In the Boston study, for example, selected supplemental work was done to refine vertiport siting criteria, determine business interest, and obtain commitments from jurisdictions for proposed regulations. No decision has been made to proceed with a second round of AIP vertiport planning that would include site selection and master plans for individual vertiports.

Currently, vertiport planning is eligible and may be undertaken by local entities such as metropolitan planning organizations (MPO) or states as a nominal part of AIP airport system plan projects. In addition, proposed individual airport or heliport master planning may consider the implications of tiltrotor aircraft and vertiport design standards if the AIP or PFC cost is nominal.

An appropriate approach to the development of CTR infrastructure may be to build vertiports in stages. This could be accomplished both for individual facilities and for networks. The Dallas Convention Center facility is an example of how this could be done for an individual site. In the first of several phases, this AIP-funded facility was designed and constructed as a large, public heliport. In the next phase, this landing site is designed to be expanded to a public vertiport.

During the next several years, the FAA does not plan to approve AIP or PFC projects that

include development exclusively for CTR. For example, while the FAA would consider approving a large commercial heliport, it would not approve exclusive CTR requirements (e.g., larger pavement or structural reinforcement beyond what is needed to support helicopter operations). This FAA policy can be expected to change and allow the planning and construction of stand-alone vertiports when the joint commitments of various organizations provides a legitimate justification that vertiport investment will lead to CTR commercial passenger operations and a significant benefit to the nation.

The planning and development requirements needed to gradually incorporate CTR aircraft into the National Airspace System and metropolitan or state systems may be relatively minor in the near future. A phased program to plan the necessary improvements, as related airport or heliport facilities evolve, can be accomplished under today's AIP or PFC programs and policies. The ultimate feasibility of stand-alone vertiports would surely be improved by selected advanced planning for appropriate airports and heliports to accommodate vertiport standards.

Under the current AIP program, once a vertiport meets the commercial service airport criteria, it would be eligible for formula-derived enplanement funds for vertiport funding (figure D2.3.1-1). Under the current law, these AIP enplanement funds would be reduced by 50 percent if PFCs were authorized.

Annual Enplanements	Annual Funding
2,500 to 70,000	$500,000
100,000	$650,000
300,000	$1,190,000
500,000	$1,700,000
800,000	$1,900,000

Figure D2.3.1-1 Enplanement Funds

D2.3.2 Passenger Facility Charges

The PFC program was added in 1990 to allow commercial service airports to impose fees for each enplaned passenger. PFCs are fees imposed by an airport for each paying passenger of a commercial airline enplaning at that airport. PFCs are considered local funds, not Federal grants, although FAA approval is required to impose and use the fees collected. To date, the FAA has approved the imposition of PFCs totaling $11.24 billion for current and future projects.

Vertiports would be eligible for PFC funding under the same criteria as airports. In a start-up mode, a vertiport may not immediately have sufficient passenger service to justify the imposition of a PFC. However, the vertiport could be funded from PFCs imposed at an airport or other facility if the vertiport was under sufficient control of a public airport agency with PFC authority.

D2.3.3 FAA Facilities and Equipment Program Funding

Vertiport facilities and equipment required in the National Airspace System may be funded from the FAA Facilities and Equipment (F&E) Appropriation. These include air traffic control towers when appropriate (see section D4.4), and government-furnished equipment (GFE) such as automated surface observation system (ASOS), global positioning system (GPS) ground station, and Mode S squitter (see section D5.2 for further discussion).

D2.3.4 Other Federal Grant Programs

In addition to AIP grants, there may be grant funds available through other agencies for the infrastructure required to support a vertiport. For example, access roads could be funded through Federal Highway Administration (FHWA) programs and mass transit systems could be funded through Federal Transit Administration (FTA) programs and the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. ISTEA is a legislative act comprised of numerous provisions that are basically reauthorizations and/or exten-

sions of existing statutes. The portion of ISTEA that appears to be most relevant to vertiport development is Title V, "Intermodal Transportation." The stated policy objective underlying Title V is the development of innovative intermodal transportation systems to enhance transportation efficiency and to strengthen the nation's competitiveness in the global economy. In addition, ISTEA contains what appears to be special legislation for specific projects related to the development of transportation systems. ISTEA established requirements for multi-modal system planning, consideration of environmental effects, and other community impacts. These are administrated through MPOs. It should be noted, however, that these programs have historically put a low priority on airport access projects and that higher priorities usually leave little funding for such projects.

D2.3.5 State Programs

State programs represent another possible source of funding. The types and amounts of funding available at the state level differ from state to state. Some states collect user fees, have dedicated funding appropriated through legislative channels, or may be amenable to special legislative programs. They may have their own grant programs or may assist airport owners by providing the local matching funds for Federal grants. State participation, or approval, may also be necessary in Federal grant programs. The threshold question in each case, however would be whether, under the laws and grant programs of any particular state, a vertiport would qualify for the same treatment as an airport or heliport, or whether special legislation would be required.

D2.3.6 Local Programs

Local governments may also have other funds available for vertiport development, including economic development grants or loans. These funds may be for aviation-related projects, but may also be designated for infrastructure necessary to the development of a vertiport. Local governments can use tax-exempt financing methods, such as bonds or other tax incentives, to foster vertiport development.

Even if Federal and state contributions are available, local entities operating airports may still need to contribute sizeable portions of the funding for capital development. For example, Federal and state grants generally require a local match that, depending on the eligibility criteria, may take the form of PFCs, bond financing, airport revenues, deeded local property, or government general funds. In order to obtain any direct funding from a municipality general fund, however, the municipality would have to be convinced of the benefits of the vertiport to the community.

D2.3.7 Bonds and Tax Incentives

Bonds are a form of financing available to both the public and private sector. Public sector bonds are ordinarily tax-exempt, while private sector bonds are not. However, the private sector may enter into an arrangement for tax-exempt financing of private ventures under certain conditions. Tax-exempt financing is a common method for local governments to provide financing for airport development. Consequently, vertiports, publicly owned for public-use, would arguably be eligible for tax-exempt financing.

It is critical in the use of any bond financing that there be an assurance that sufficient revenues are identified to repay the obligation. Consequently, if such financing were to be used in the development of a vertiport, the economic feasibility of the vertiport must first be determined and revenues must have been pledged for the repayment of bonds.

Although not a method of financing, tax incentives may be another method of enhancing the economic feasibility of this type of project, much like grants, PFCs, or contributed capital that would constitute "equity."

D2.3.8 Private Grants and Gifts

Private vertiports used for private purposes would be the most obvious beneficiary of private funding. However, governmental entities may

occasionally receive grants or gifts of property from the private sector to construct new infrastructure that would be owned by the governmental entity and used for a public purpose. The motivation of the private sector grantor may be to increase its property values or the marketability of its own enterprise. One example would be for a private sector party to contribute to the development of a vertiport because that party owns land and/or office buildings that would be adjacent to the new vertiport.

D2.3.9 Private Funding

In the current atmosphere of Federal budget constraints, shrinking federal airport grant funds and competition for those funds, AIP grants may not be available for the bulk of vertiport acquisition, construction, and implementation costs. If this is the case, the primary source of funding would have to be private investment and financial feasibility would have to be demonstrated.

D2.3.10 Public/Private Partnerships

This category raises various possibilities. Such a partnership would probably require the governmental entity to act in an entrepreneurial capacity, rather than in its traditional sovereign capacity. The facilities developed with this financing arrangement would still need to be used for a public purpose.

Implementing a CTR short-haul transportation system will require parallel decisions by Federal, state and local governments along with operators and manufacturers. To assure proper planning, focus, and coordination of decisions, a jointly funded partnership could be established to test the feasibility of establishing the required ground infrastructure and to monitor the results of aircraft and air traffic research.

Such a partnership would involve a contribution from each of the organizations involved. The Federal contribution could be management personnel and the funds required for detailed planning of the various vertiport networks. The contribution from the states, metropolitan governments, and industry could be the labor of their various personnel and the standard AIP state and local matching funds.

D3.0 Ground Infrastructure

Vertiports are the basic component of the ground infrastructure system. The major issues associated with the planning and design of vertiports are site selection and acquisition, facility design, construction, compatible land-use planning, intermodal transportation, and operating regulations.

D3.1 General Vertiport Characteristics

In fiscal year 1988, the Federal Aviation Administration (FAA) funded a program of vertiport feasibility studies (reference 9) in anticipation of advanced vertical flight aircraft, such as the civil tiltrotor (CTR), being used for scheduled passenger service. The purpose of these studies was to identify areas in the U.S. where the potential for such aircraft application would be greatest so that infrastructure requirements could be identified and implemented in a timely manner. These studies used the CTR-22C, the aircraft then anticipated to be the first civil tiltrotor, as the design aircraft. These feasibility studies specifically recognized that vertiports would be developed primarily for scheduled service passenger operations, with the business traveller as the principal passenger.

Vertiports supporting scheduled passenger service would require all-weather operations, one or more touchdown lift-off surfaces (TLOF), multiple-gate passenger terminals, associated rental car/parking facilities, CTR fueling, and limited maintenance capabilities. It is now envisioned that vertiports may accommodate various size CTRs in support of passenger and small package cargo, as well as helicopters that would perform a variety of shorter-range missions.

The potential public benefit of planning and designing vertiports to incorporate other modes of transportation has recently received greater recognition because it would provide a variety of transportation alternatives at one location. CTR use at vertiports may also be complemented if built in conjunction with multi-modal transportation centers, parking garages, office complexes, or shopping centers, etc. This type of vertiport may broaden the constituency of public and local government support for the facility, attract more potential passengers, and potentially provide additional sources of income for all services sharing a location.

D3.2 Vertiports and Design Criteria

It is expected that vertiports will provide passenger-oriented services similar to those available at hub airports. In meeting these expectations as well as the airside requirements, vertiports will require specific design criteria that enhance their function and their safety while minimizing their economic and environmental impact on the surrounding local community. Thus, while vertiports will be small in physical size when compared to hub airports, they may be sophisticated facilities. Figure D3.2-1 shows an example of a large public-use vertiport. Figure D3.2-2 shows an example of a small public-use vertiport.

D3.2.1 Design Issues

The design of vertiports is presently addressed by FAA Advisory Circular (AC) 150/5390-3, "Vertiport Design" (May 31, 1991) (reference 10). This AC was developed over a period of several years by an FAA/Industry working group that found it necessary to make a significant number of assumptions. The AC includes definitions and design requirements for the physical aspects of vertiports such as the final approach and takeoff area (FATO), TLOF, specifications for visual flight rules (VFR) and instrument flight rules (IFR) approach surfaces, marking, lighting, and navigation aids. Landside AC design issues currently address pas-

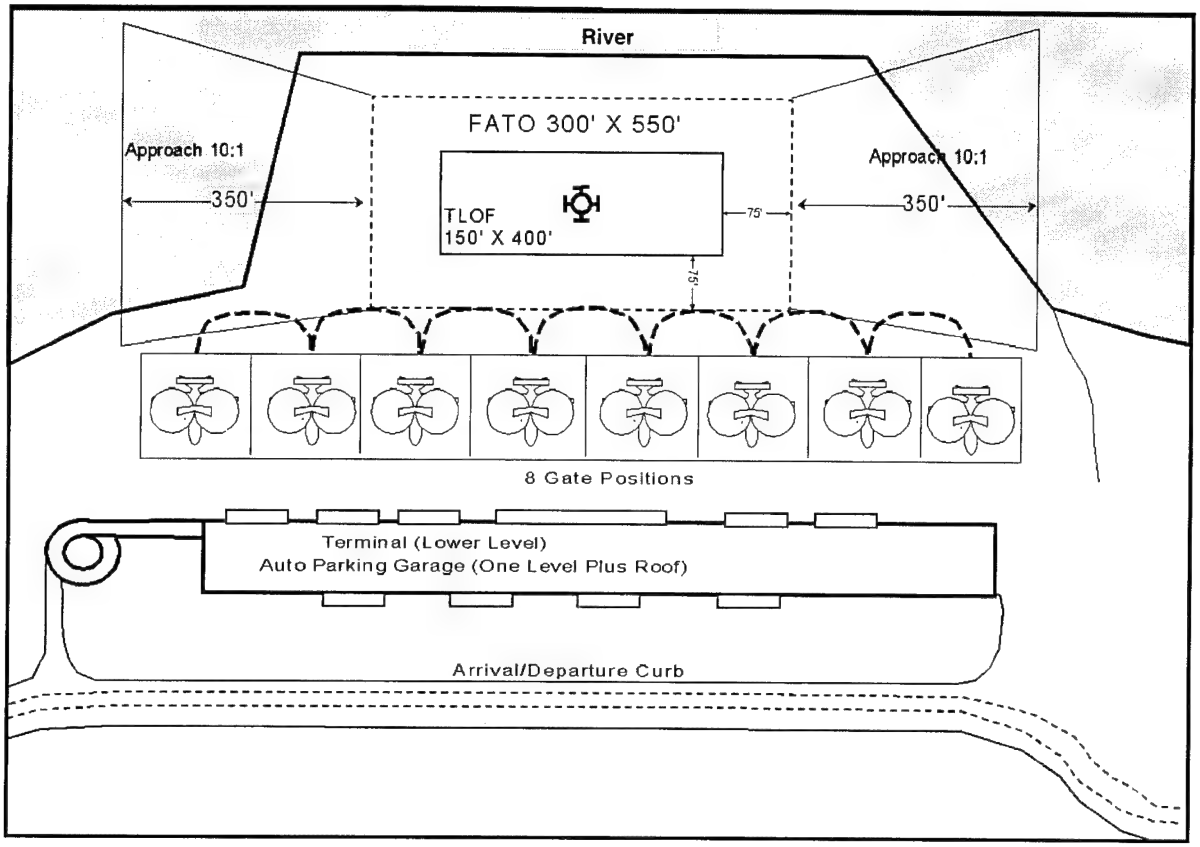


Figure D3.2-1 Large Public-Use Vertiport

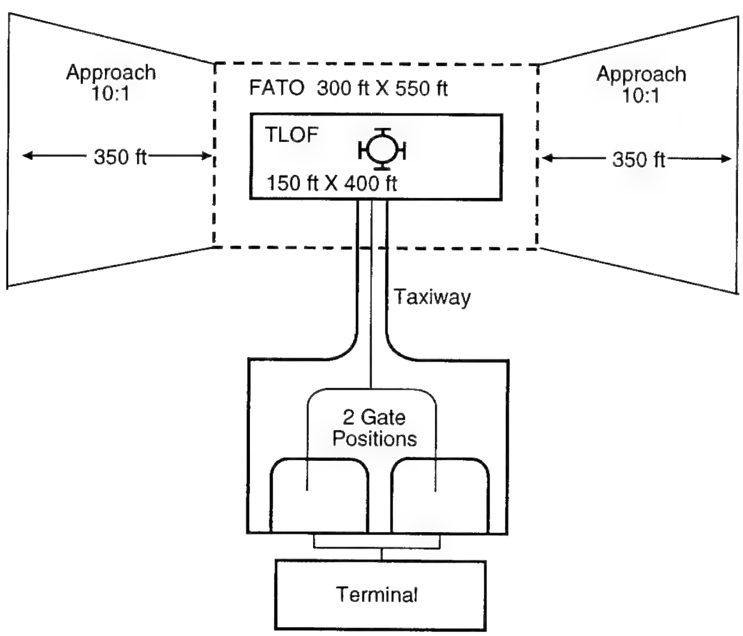


Figure D3.2-2 Small Public-Use Vertiport

senger services, hangars, parking, and fuel storage. However, recent research initiatives by the FAA and the National Aeronautics and Space Administration (NASA), as well as advances in technology leading to an increased understanding of CTR capabilities, have indicated the need to update this design AC. Recognizing this, the FAA has formed a working group to revise the Vertiport Design AC.

The FAA/industry working group that developed the current design AC used the CTR V-22C, which at that time was anticipated to be the first CTR, as the design aircraft. A more recent design of the aircraft expected to be first CTR, the CTR2000, has been used in the Civil Tiltrotor Development Advisory Committee (CTRDAC) effort. The CTR2000 design incorporates the findings of current research regarding CTR capabilities and operational requirements. Additional research and development (R&D) topics that have been identified as necessary for specific vertiport AC design criteria include: guidance related to instrument approach angles; air traffic pattern procedures; aircraft separation standards; wake turbulence; facility capacity; marking; lighting; and standard procedures for assessing the impact of a high-activity facility on VFR activities in the surrounding airspace.

In addition, noise criteria for land-use planning, perhaps the key to community acceptance, need to be extensively examined for their impact on vertiport design and operational procedures. Noise research needs to include the impact of all types of aircraft (i.e., CTRs, helicopters, and general aviation [GA] aircraft) that will be operating from off-airport vertiports or vertiports incorporated into commercial and GA airports.

Other critical vertiport airside design issues identified that are not yet discussed in sufficient detail in the present AC include:

- Rejected takeoff requirements.
- Facility design features that support Category A operations.
- Rollway length and facility sizing requirements as a function of density altitude.
- Characteristics of the baseline CTR aircraft design that should be used in sizing vertiport facilities.
- Refinement of a methodology for defining vertiport capacity and delay as related to an arbitrary vertiport configuration or system [some recent work on this subject (reference 11) indicates that airspace separations and gate availability may be the key issues under some scenarios and not TLOF occupancy time].

Landside vertiport design needs to address numerous issues such as passenger services, baggage handling, fire and rescue equipment, security, fueling, deicing/anti-icing, hangars, parking, and fuel storage.

D3.2.2 Rotorwash/Wake Vortices

Rotorwash is the flow of air induced by the rotors when a CTR is moving at slow speed in close proximity to the ground. This downward flow strikes the ground and spreads out in all directions.

Wake vortices are the deflected airflows behind the wings and/or rotor blades of an aircraft in flight. The rotating components of these airflows shed off the wings/rotors, combine, and descend in altitude as they diminish in strength. The strength of CTR and rotorcraft vortices is inversely proportional to airspeed at airspeeds above 40 knots.

Since the majority of civil helicopters are light in weight, it is rare for their rotorwash to cause property damage while hovering or taxiing. It is also rare that they become involved in airborne wake vortex mishaps. FAA studies of these safety issues (references 12 and 13) have revealed that large military helicopter operations have caused these types of mishaps and that specific operational procedures must be followed for safety. The 40-passenger CTR is expected to be similar in weight to the large military helicopters. Thus, for ground operations and for approach/departure, specific CTR operational procedures will need to be developed.

Rotorwash must also be considered in the design of vertiports to ensure that operational procedures are developed for approach, departure, taxi, and gate operations of CTR aircraft to protect personnel and other aircraft in close proximity to TLOF and gate areas. Separation criteria, particularly if CTRs are allowed to load/unload passengers with engines operating and rotors turning, may require the use of loading bridges to ensure passenger safety. These structures would be similar to jetways currently used at airports and would also provide vertiport security so that passengers will not be able to wander onto the vertiport tarmac. The vertiport AC also needs to reflect typical rotorwash velocities to enable designers to calculate rotorwash effects on windows, doors, roofs, and finishes of vertiport structures since loads and windblown abrasive particles must be considered in the design of these building components.

Design standards must be developed for surface pavements since high-temperature engine exhaust may be directly aimed at the pavement during CTR hover operations. Some proposed CTR vehicle designs are expected to eliminate engine exhaust/pavement problems.

Large helicopter wake vortices have been measured experimentally. These measurements clearly indicate that wake vortices have the potential to upset small fixed-wing aircraft and helicopters at significant distances. No experimental wake vortex data have been measured for the current V-22 tiltrotor. Limited analytical work indicates that wake vortex strength will be similar to large helicopters. Therefore, additional research must be conducted to evaluate the potential wake vortex/rotorwash hazards that CTR aircraft might create, particularly for small aircraft, as well as to define operational procedures to alleviate those hazards.

D3.3 Vertiport Planning and Land-Use

The benefit of a well-planned system of vertiports is foreseen to significantly increase the potential success of introducing the CTR into civilian service. Such a system must take full advantage of the lessons learned in the last five decades of airport planning with particular attention to land-use compatibility and quality of life considerations for communities.

D3.3.1 Vertiport Planning

The most critical aspect of planning is that individual facilities must be situated near peak passenger demand locations. The number and size of vertiports should be determined by the demand for such service. Once demand is confirmed, other issues regarding siting need to be addressed. For example, will the vertiport be located on an existing airport or as a stand-alone facility in either an urban or suburban location. Key considerations are community acceptance, type of ownership, land-use compatibility, zoning, and land acquisition. Although most land-use regulation is administered and applied at the local level (i.e., cities, towns, counties, etc.), planning for a vertiport system would require a cooperative effort among Federal, state, Metropolitan Planning Organizations (MPO), and local government agencies.

To provide the capacity needed to handle the number of passengers required to make a scheduled air carrier system feasible, a typical ground-level vertiport will require approximately 20 to 30 acres. Elevated/multilevel facilities will to require approximately 10 to 20 acres. In order to mitigate noise impacts, a vertiport should be located where the surrounding area has stable compatible land uses such as rivers, lakes, industrial parks, rail yards, freeways, flood plains, etc. Some regulation, such as zoning or restrictive easements, may be required to preserve the stability of this compatible land use pattern. The size of this surrounding area will be depend on the nature of the adjacent land use. Industrial and business land uses are normally compatible with noise levels below DNL 75 dB and DNL 70 dB respectively. Residential uses are normally compatible with noise levels below DNL 65 dB. The size of the noise exposure contours are shown in figure D3.3.1-1.

Noise Level	Contour Area (approximate)
DNL 75 dB	12 acres
DNL 70 dB	44 acres
DNL 65 dB	119 acres

Figure D7.0-1 Noise Exposure Contours

Sites of 119 acres in close proximity to passenger demand centers are very difficult to locate. Desirable sites of 25 acres and 44 acres are somewhat less difficult to find. While the amount of land required for vertiports is much less than those for a conventional airport, locating the vertiport near the demand center is expected to be a challenging task in many cities.

D3.3.2 Zoning

Zoning is the principal form of regulation available under the general police power of most municipalities to promote orderly development of communities and protect local citizens from annoying and harmful effects of incompatible activities juxtaposed on the land. However, zoning has generally proved ineffective in protecting landing sites from the development of noise-sensitive development in nearby adjacent areas unless it is done years in advance. It may be effective in discouraging, or actually preventing, the development of noise-sensitive housing and related facilities near airports, but only if the extent of the airport-related effects, such as aircraft noise, are well known in advance. Once established, zoning is difficult to change because it always affects the value of property rights to some degree. Zoning is a major factor in obtaining community acceptance of aviation facilities.

It is unlikely that CTR systems will require numerous vertiports in areas within municipalities that are already zoned against the introduction of transportation noise sources. Most localities can be expected to permit the construction of heliports or vertiports only as special exceptions in any designated zoning district. Localities can be expected to require explicit information about CTR operating characteristics, including takeoff and landing noise contours, in order to provide an analytical basis for the special permission that would be needed to accommodate the new technology. Such information would have to be incorporated according to varying standards in local zoning ordinances as part of the process of authorizing each vertiport and protecting it from encroachment by incompatible development and from political interests. Such information should be available to localities expected to make such changes in their zoning laws.

D3.3.3 Land-Use Planning

Planning for compatible land usage in the environs of any aviation facility is an enduring challenge to airport operators and local communities. It will be essential to the success of any vertiport infrastructure development to ensure, through land-use planning, that noise-sensitive activities, such as housing and schools, are not permitted in the areas adversely affected by aircraft noise.

The purpose of this section is to present vertiport land-use planning in perspective. The anticipated system of vertiports is expected to cover many local, regional, and even state jurisdictions. Vertiport land-use planning efforts will encounter numerous agencies at the Federal, state, and local levels that affect not only the land-use, but zoning, design, construction, and operation of the vertiport facilities. Of particular importance will be environmental impact described in greater detail in the CTRDAC subcommittee report on environmental issues.

- *Local*

Planning is a fundamental obligation of local governments throughout the U.S. Most states require that the cities, towns, villages, etc., within their boundaries prepare and generally follow plans that help to ensure orderly development and the protection of the public health, safety, and welfare

of their citizens. Such plans, usually termed *general* or *comprehensive* plans, in contrast to functional plans, form the basis for the local regulations that determine land use, transportation, and other capital investment decisions for municipalities.

Most of the major cities in which CTR service is most likely to be introduced have requirements for comprehensive development planning. Such planning should include transportation systems and could provide the framework for selecting vertiport sites in relation to community facilities and associated proposed development. This would be consistent with Federal requirements for multimodal and intermodal transportation under the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 and the Clean Air Act Amendments of 1990. It would further emphasize the need to present vertiports as defined elements of the transportation plan of each locality.

- *State*

A few states have established active programs to encourage or require their municipalities to participate in statewide planning activities for specialized facilities or resources, such as airports, major highways, and environmentally sensitive coastal zones. In some instances, the state reserves the right to modify local land-use and zoning regulations that the state finds contrary to the long-term interests of its key aviation facilities. This level of state involvement in local comprehensive land-use planning helps to keep aviation interest in perspective and serves to prevent the most egregious forms of incompatible local land-use from being pursued for short-term gains in the marketplace.

- *Metropolitan*

Given the essentially state/metropolitan scope of the recent ISTEA legislation and regulations, it would be logical to incorporate the study of proposed vertiports into the metropolitan and state planning that ISTEA requires. It would be particularly important to define the intermodal relations of the operational CTR systems. Planning for major transport systems that encompass several local government jurisdictions must be conducted by metropolitan agencies. At the present time, MPOs only rarely constitute planning for specific facilities, such as vertiports, or the implementation of particular plans. However, due to ISTEA, these agencies will undoubtedly play a significant role in analyzing options and evaluating the desirability and public benefits of CTR as part of the local air transportation system.

D3.3.3.4 Federal

ISTEA provides mandates for MPOs. Sections 1024 and 3012 of ISTEA describe the MPO role in transportation planning for urban areas. Although MPOs were created in 1975 to implement the urban transportation planning requirements of the Federal Housing Authority (FHA) and the Urban Mass Transportation Administration (now FTA), ISTEA has added an important factor to MPO responsibilities that relate to vertiport infrastructure development in that the new planning requirements have a much stronger intermodal emphasis (reference 14). Now, MPOs are required to develop plans and programs for multi-modal transportation systems in urban areas and are further directed to consider all modes of transportation, presumably, including CTRs. It does not appear, however, that funds are available under these sections of ISTEA.

D3.4 Aviation Regulations

Vertiport development is subject to numerous regulations at the Federal, state, and local levels. These regulations affect the land-use, zoning, financing, design, construction, and operation of the vertiport facilities. Of particular importance will be those regulations relating to land-use compatibility and environmental impact. The full impact of these regulations will depend on the location and function of the vertiport, whether it is located on an existing airport or stand-alone, whether it is located in an urban area or suburban area, the scope of the facilities to be included as part of the vertiport, and whether there will be a network of facilities cutting across a number of jurisdictions. (For the full impact of environmental concerns and regulation see the Subcommittee Report on environmental issues.)

D3.4.1 State and Local Regulations

Some states have specific heliport regulations that are separate from airport regulations but the majority do not. Nevertheless, even those states not directly concerned with heliports may affect the development of vertiports through a variety of statutes and regulatory requirements pertaining to environmental issues.

At a minimum, municipal regulations may encompass permits, land-use, zoning, fire protection, operation control, safety, insurance, etc. There may be overlapping or conflicting requirements arising from jurisdictional disputes. These would need to be resolved in order to implement the project.

D3.4.2 Federal Regulations

Because vertiports are included in the definition of airports, the Code of Federal Regulations (CFR) will affect vertiport establishment, operation, and maintenance. The extent of Federal regulation is dependent on the type of ownership (i.e., public or private); if the financing was provided by private funds or if Federal grants were received; and the type of aviation operations to be conducted (e.g., private or scheduled air carrier). At a minimum, vertiports providing scheduled air carrier service can be expected to be regulated by 14CFR77, "Objects Affecting Navigable Airspace"; 14CFR107, "Airport Security"; and 14CFR139 "Certification and Operation: Airports Serving CAB Certified Air Carrier Aircraft". If the vertiport is collocated on an existing airport, many of the applicable 14CFR107 and 14CFR139 requirements may be satisfied by the existing airport operating plan or certification manual.

The requirements of 14CFR77 prescribe airspace limits surrounding airports and establish a requirement for notification of intent to build antennas, buildings, or other potential obstacles in the vicinity. Objects that penetrate those surfaces are classified as obstructions and require an aeronautical study to identify the actual effect on navigable airspace. The text of 14CFR77 does not mention vertiports specifically and what it says about heliports is in need of revision.

A scheduled air carrier airport or vertiport must meet the security requirements of 14CFR107 that requires a method or procedure to control access to the secured airport areas to ensure that only authorized persons are able to enter.

14CFR139 prescribes rules governing the certification and operation of land airports that serve any scheduled or unscheduled passenger operation of an air carrier that is conducted with an aircraft having a seating capacity of more than 30 passengers. Any airport in this category must apply to the FAA for certification.

Under 14CFR139, airport operators are required to establish an airport certification manual containing procedures and requirements for airport personnel, paved and unpaved areas, safety areas, marking and lighting, snow and ice control, aircraft rescue and fire-fighting, handling and storing of hazardous materials, airport emergency plans, self-inspection programs, ground vehicles, obstruction removal, protection of navigational aids, public protection, wildlife hazard management, airport condition reporting, and handling noncomplying conditions.

Federal grant funding and 14CFR139 requirements essentially make compliance with certain FAA series 150 ACs mandatory. Facilities such as aircraft rescue and fire fighting (ARFF) buildings may be required, as well as the appropriate ARFF equipment and airfield security required by 14CFR107. In addition, a minimum level of staffing may be required with specific training and record-keeping procedures that must be followed and documented. ARFF staffing significantly increases the cost of operating a facility, although Federal grant funding normally is available to help defray the cost of providing the equipment and buildings needed. In addition, compliance with 14CFR139 does not necessarily meet the National Fire Protection Association (NFPA) Standards that can be mandated by state and local governments. Additional staffing and full compliance with NFPA standards can further increase costs.

D4.0 Air Infrastructure

Air infrastructure issues concern whether or not the civil tiltrotor (CTR) will be able to operate within current, and foreseen future, air infrastructure systems. These concerns encompass CTR impacts on terminal and en route airspace capacity and productivity, and any changes that may be needed to airspace communication, navigation, surveillance and control procedures, or to regulations.

D4.1 CTR Impact

CTR operations are expected to be integrated into the airspace system that is in place at the time service is initiated. For the most part, the CTR is expected to be handled in the en route system like a modern-day, high-performance turboprop aircraft (reference 15). Based on the CTR2000 conceptual design, the aircraft is expected to be equipped with a modern transport flight deck and have a large contingency-power rating for one-engine-inoperable (OEI) capability. The flight deck is expected to include a flight director or equivalent, coupled autopilot, navigation, and guidance equipment based on the global positioning system (GPS) wide area differential or local area differential capabilities to support both en route and terminal operations. Preliminary analyses by the Federal Aviation Administration (FAA) (references 15 and 16) indicate that the CTR can be accommodated and its unique capabilities can be used to an advantage in the existing terminal and en route air traffic control (ATC) environment with minimal impact. Furthermore, it is not likely that the introduction of CTR service will cause significant impact on controller workload or lead to overloaded sectors in or around terminal airspace.

D4.2 Research and Development

Further research and development (R&D) is necessary in areas associated with vertiport design criteria, air traffic pattern procedures, aircraft separation standards, wake vortices, and the impact on surrounding airspace resulting from a high-activity CTR facility. In addition, there is limited information on the size of the terminal instrument procedures (TERPS) airspace that would be required to accommodate CTR precision approach and departure procedures and on how such procedures may impact existing airspace or air traffic patterns for both visual flight rules (VFR) and instrument flight rules (IFR) operations. Information on these topics should be developed and provided in the appropriate FAA publications.

Preliminary studies by the FAA, the National Aeronautics and Space Administration (NASA), and industry have demonstrated those issues associated with a steep approach field-of-view to a vertiport and approach lighting present a greater challenge than that associated with the typical 3-degree approach angle. R&D projects are investigating these issues. Potential transfer of technology used by the Department of Defense (DoD) to civil applications seem to offer elementary lighting and visual recognition systems that could be used for vertiport instrument and visual approaches. TERPS will need to be developed that reflect CTR characteristics and GPS receiver design. CTR GPS receivers may need special adjustments in display sensitivity.

Criteria for establishing and operating control towers (class D airspace) at vertiports need to be developed. Preliminary assessments support the need for some level of air traffic authority compatible with these potentially high-activity facilities. These assessments would address whether the ex-

isting airport air traffic control (ATC) tower criteria are appropriate or if they should be modified to develop specific vertiport criteria. Many vertiports are likely to be operating beneath, not within, the floor of either class B and C airspace. Thus, guidelines should be developed for implementing and designating the appropriate airspace at vertiports when the facilities are located under already existing controlled airspace.

Techniques for analyzing airspace impacts, particularly on high-density rotorcraft operations in the vicinity of proposed vertiports, need to be refined and standardized so they can be used by regional FAA personnel. This should be done both for stand-alone facilities and for facilities located on airports. The FAA should provide guidance on how to assess impacts on local and regional airspace if controlled airspace is designated around a vertiport. This is of particular concern in an area like Manhattan since there is a significant amount of VFR traffic along the rivers being considered as vertiport locations.

D4.3 Satellite Technology

Both the GPS and automatic dependent surveillance (ADS) technologies add a new dimension to the ATC system and should be well suited to CTR operations. No revisions to basic air traffic systems other than these are considered essential to support CTR air carrier services.

D4.3.1 Global Positioning System

Preliminary GPS navigation testing is underway by the FAA, NASA, and industry and offers the potential to reduce airspace requirements associated with navigational accuracy and obstacle clearance surfaces. These investigations have shown promise in enhancing navigational accuracy and offering the potential to reduce TERPS airspace requirements as well as enhancing ATC separations standards. These changes are expected to augment the unique operating characteristics of the CTR that enable it to operate to and from urban and suburban vertiports.

D4.3.2 Automatic Dependent Surveillance

The use of satellites has dramatically increased during the 1990s and will continue to expand into the next century. As an example, efforts are being made to use digital satellite data links to transmit aircraft position reports to an ATC facility. This should be especially useful in areas where current limitations in radar technology associated with the effects of ground obstructions and terrain have encumbered automated aircraft position reporting. These enhancements, known as ADS, can be used via satellites and associated technology to pinpoint the exact location of an aircraft without interference from ground obstructions or limitations in the signal strength of ground-based navigational aids.

D4.4 Vertiport ATC Tower Establishment Criteria

Some vertiports are expected to be located at major airports with existing ATC towers. At other vertiports, ATC services are expected to be provided by existing towers in the same geographic area. At some vertiports, however, the number of operations are expected to require an on-site tower. In the estimate of vertiport costs, the cost of an ATC tower has been included for stand-alone vertiports that are expected to have 38,000 or more annual 40-passenger CTR operations. In the absence of a specific criteria for a vertiport tower, the 38,000 threshold is based on the number of annual air carrier operations required to justify a tower at an airport (reference 17). An FAA criteria for establishing vertiport control towers needs to be developed.

D5.0 Costs and Revenues

Cost has been examined at two levels. The first level involves the individual facility itself, whether a stand-alone vertiport, a separate facility on an airport, or for necessary preparations to use runways and terminal facilities at an existing airport. The second level of cost is for a complete system of vertiports.

An issue closely associated with costs are potential revenues that can be expected to be derived from the vertiport and how well these revenues meet the cost of its operation.

D5.1 Generic Facility Costs

Figure D5.1-1 shows a generic range of costs for different types of civil tiltrotor (CTR) facilities at three typical locations. The costs are based on a mathematical model developed at the Volpe Transportation System Center (VNTSC). The model determines the size of specific vertiports based on the expected annual number of passengers, its location (i.e., urban, suburban, or airport) and type (i.e., elevated, ground, or pier). It then calculates the cost for the vertiport, including land. To develop the range of generic cost estimates shown in figure D5.1-1, the requirements for vertiports representing the smallest and largest facility for each location and type were input into the model.

Location	Type	Cost Range (in millions of dollars)
City center	Elevated vertiport	10 to 40
	Vertiport on new pier	90 to 125
Suburban	Ground vertiport	6 to 20
	Elevated vertiport	10 to 25
Airport	Existing facility	0 to 10
	New airside facility	2 to 17

Note: Upper end of cost ranges does not include full cost of noise or environmental mitigation

Figure E5.1-1 CTR Generic Vertiport Cost Range

Including all structures and equipment, the expected capital costs for one vertiport varies from no cost, when using runways and other facilities located at an existing, uncongested airport, to about $125 million for a high-capacity, stand-alone vertiport on a new pier in a downtown urban area.

D5.2 Estimated CTR System Costs

Figure D5.2-1 shows the expected nature of the individual facilities in the four primary CTR systems: Northeast Corridor, Mid-West, West Coast, and Southwest. An estimate was also developed for the cost of these four vertiport systems (figure D5.2-2).

The CTR system cost estimate is based on two of the three markets described in section D2.2. The Economic Subcommittee regarded the third market, transfer passengers, as uncertain and did not include these potential benefits in their benefits summary. Because the potential benefits of this market have been disregarded, no costs are calculated here.

A CTR system cost estimate has been developed for two development and construction phases. Phase 1 represents a start-up system of six landing facilities in the Northeast Corridor. Phase 2 represents a full network of approximately 24 additional landing facilities in the four primary study areas. Phase 2 is an established system, urban/suburban area to urban/suburban area, plus limited airport feeder locations.

	Northeast Corridor Phase 1	Northeast Corridor Phase 2	Midwest	West Coast	Southwest	Total
Existing commercial airports	2	1	2	2	1	8
Existing general aviation airports	2	2	1	1	-	6
Existing heliports	2	-	-	-	1	3
New sites	-	3	5	3	-	11
Total	**6**	**6**	**8**	**6**	**2**	**28**

Figure D5.2-1 Proposed CTR Landing Sites

	Cost (in millions of dollars)
Northeast corridor - Phase 1	67.5
Northeast corridor - Phase 2	279.5
Midwest network	161.0
West Coast network	138.6
Southwest network	19.7
Public/private partnership	9.4
Total infrastructure cost	**675.7**

Figure D5.2-2 Estimated CTR System Costs

Included in the cost estimates shown in figure D5.2-2 are vertiport planning, environmental impact statements, land acquisition, facility design and construction (including crash/fire rescue equipment and security costs), air traffic control towers when appropriate (see section D4.4), and government-furnished equipment (GFE). GFE includes the following:

- An automated surface observation system (ASOS), costing $175K; one per vertiport site unless located at a large airport where weather information is assumed to already be available.
- GPS ground station, costing $50K; one per city to provide accuracy that would allow Category 2 and Category 3 CTR operations.
- Mode S squitter transponder, costing $150K; one or two per city as appropriate.

The cost for implementing the first six landing facilities in the start-up Phase 1 CTR infrastructure is approximately $67.5 million. The approximately 22 additional Phase 2 landing facilities (figure D1.3-1) are estimated to cost $599 million. Public/private partnership costs are estimated at approximately $9.4 million for system planning and decision coordination. This total cost of $676 million is for a program of approximately 10 years of planning, design, and construction. This is a significant cost. By comparison, however, a single IFR runway at a major airport can cost $80 to $500 million, including associated lighting and navigation equipment. The typical public-use vertiport, as sized to support short-haul commuter service, is expected to accommodate between 50,000 and 800,000 annual enplanements. In calendar year 1993, the top 50 major airports handled between 2.6 and 30 million annual enplanements.

D5.3 Vertiport Revenues

In addition to the funding discussed in section D2.3, vertiport revenues are included in vertiport financial planning. Of particular interest is paying vertiport costs during the early stages when the vertiport may not yet be self-sustaining. If the vertiport charges and fees are high enough to cover all of the costs, the fees and charges may be too high, making it economically impracticable for operators to use the facilities. On the other hand, if the rates are insufficient to cover all of the costs, other sources must be found to fund the deficit.

An airport or vertiport can receive monies from the "system" or authority in which it exists. In turn, if the airport or vertiport is making money, it may contribute to other facilities in that system.

- *Aircraft Operator Fees and Charges*

Revenue can be generated from aeronautical users of the vertiport in the form of rent, landing fees, or other comparable charges for the use of vertiport facilities. Under current law, these fees and charges must be reasonable and bear some relation to the party's use of the vertiport unless otherwise agreed upon by the parties. Other potential sources of revenue are fuel sales, aircraft maintenance, hanger fees, aircraft handling, etc. An additional source of funds may be to provide cargo service for small high-value items that could be included on a scheduled regional flight that would otherwise serve only passengers.

- *Enplanement Funds/PFCs*

To the extent that enplanement funds are available at a particular vertiport, these funds can be used to repay the land acquisition, construction, and implementation costs. The current AIP program does not permit use of grant funds to service past construction debt. Passenger facility charges (PFC) are currently limited to $3 per enplanement. A recent attempt to raise this to $5 was unsuccessful.

- *Non-Aeronautical Revenues*

At airports, non-aeronautical revenues consist primarily of revenues from parking and from concessions, such as restaurants, retail shops, rental cars, wall advertising space, and hotels. These sources often provide as much as one third of the revenue of an airport. However, vertiports are not expected to have as much concession space as an airport and passengers are not expected to spend as much time in a vertiport as in an airport. Thus, vertiport concessions revenue are expected to be significantly smaller than airport concession revenues.

While the percentage of passengers who will park at a vertiport is difficult to forecast accurately, a premium parking fee may be appropriate at some locations. Under some circumstances, parking might also be sold to automobile commuters who work near the vertiport. Due to competition at downtown locations, parking revenue is expected to make a very limited contribution beyond covering the cost of the parking facilities. At suburban locations, parking may make a larger contribution to vertiport revenues.

Other possible sources of revenue or user fees should be explored. The availability of these various revenue sources is dependent on the location and character of a particular vertiport.

- *Vertiport Financial Options*

Analysis conducted for the Economic Subcommittee has indicated that there several options for financing vertiports (figure D5.3-1). Under three of the five options shown, vertiports would be able to repay their capital and operations and maintenance (O&M) costs. All of these options are dependent on Congressional decisions on Federal Aviation Administration (FAA) budgetary matters currently under discussion.

Revenue Sources	Revenues Less Capital and O&M Costs
$3 PFC with no AIP	- $12 million
Existing AIP formula	- $5 million
$4 PFC with no AIP	0
$3 PFC with 50% AIP allocation	+ $11 million
$4 PFC with 50% AIP allocation	+ $23 million

NOTE: Estimates include landing fees and other user charges at $125 per flight and vertiport O&M costs at $2.10 per passenger. Revenues and costs from other activities such as automobile parking and use by other aircraft are not included.

Figure D5.3-1 Vertiport Financial Options in Four U.S. Corridors in Year 2010

D6.0 Milestones

A full network of large, sophisticated vertiports will not spring into existence all at once. The manufacturers will not commit to build the aircraft if there are inadequate numbers of customers. Customers will not commit to buy the aircraft if there are insufficient numbers of well located vertiports in a coherent network. State and local entities will not commit to build large, sophisticated vertiports until they have a clear idea of what benefits the aircraft will bring to their communities. A plan and a schedule is needed to guide the transition from a start-up to steady-state civil tiltrotor (CTR) operations. Without a clear plan, it is uncertain whether anyone will break the "chicken-and-egg" circle by going first.

The timing of decision making and development for an entirely new transportation system, such as one for CTR, is an intricate process. An extremely simplified overview of agency responsibilities is shown in figure D6.0-1. Issues dealing directly with infrastructure issues are shown in bold. This figure shows a list of all the agencies involved in starting a CTR service and the major tasks they would have to accomplish.

The process that the agencies would need to pursue is further complicated by real-world issues such as potential markets, funding limitations, and the need to balance the Federal budget. Manufacturers do not want to build, and cannot afford to develop, an aircraft without some assurance that there is a ready market. The markets, or cities, do not want to build expensive facilities if there is not going to be a vehicle to use them. In the interest of planning the related efforts of the various organizations involved, there needs to be some formal mechanism for continued coordination and joint decision making regarding the development of the physical infrastructure and the aircraft. A public/private partnership could be an appropriate mechanism for accomplishing this if the Congress responds positively to the Civil Tiltrotor Development Advisory Committee (CTRDAC) report.

If the decision is made to implement a vertiport network, one of the most challenging tasks will be the development of the initial start-up vertiports. One possible first step would be for several cities to commit to building appropriately located heliports that are designed to allow an eventual conversion into vertiports when CTR is available. It is less difficult to obtain funds for construction to meet near-term needs (e.g., heliport construction based on forecasted 5-year helicopter operations) than it is to secure construction money for the longer term needs of CTR operations. Perhaps if several key cities would commit in the near future to one or two "Dallas model" heliport/vertiports, manufacturers could make a firm decision to build the 40-passenger CTR.

Agency	Responsibilities
FAA	• Certification of the aircraft • **Analysis of noise data for possible revision** • **Updating the computerized heliport noise model (HNM) to include CTR data** • **Education and training of airport personnel on vertiport development and operations requirements** • **Approval of and assistance to a civil demonstration program** • **Adoption of final standards on vertiport design** • **Incorporation of vertiports into the National Plan of Integrated Airport Systems (NPIAS) and Airport Capital Improvement Plan (ACIP)** • **Awarding AIP grants fort site-specific vertiport planning and construction** • **Revision of ACs to reference CTR/Vertiport Design Guide** • **Development of procedures for conducting airspace analysis for vertiports** • **Development and adoption of CTR IFR approach criteria to vertiports** • **Development and adoption of ATC procedures for CTR operations** • **Amendment of FARs for CTR** • **Installation and operation of National Airspace System (NAS) Plan Facilities/Equipment** • Establishment of training and licensing requirements for CTR flight crews
NASA	• Continued research and development of CTR technology • Support for the CTR demo
Department of Defense	• Completion of flight and ground testing of V-22 • Funding full-scale V-22 development and production • **Continued dissemination of V-22 flight test/operations data to FAA and NASA** • **Provision of a V-22 test aircraft for a civil demonstration program** • **Obtaining operational experience with the V-22 by Marine Corps and U.S. Navy**
U.S. Congress	• **Continued support and funding for the CTR program** • **Directing FAA to provide necessary administrative and infrastructure support**
State	• **Establishment of policy on statewide vertiport development** • **Incorporation of vertiport development into state Aviation System Plan (ASP)** • **Revision of priority rating program to include vertiports as part of ASP within mid- and long-range planning horizons** • **Revision of state regulations to include vertiport permitting and adding CTR-specific definitions** • **Support for statewide or multi-state CTR demo programs** • **Coordination with Airport Land-Use Commission (ALUC) to circulate rules and regulations for CTR operations** • **Revisions of Airport Land-Use Planning Handbook to include CTR terms of reference**
Regional and Local	• **Adoption of policy supporting CTR/vertiports** • **Conducting workshops for public officials on benefits of alternate modes of air transportation** • **Active support of CTR demo programs** • **Development of modal zoning ordinance to include vertiports** • **Revision of Airport Land-Use Plans to include CTR/vertiport terms** • **Sponsorship of vertiport feasibility and site selection studies** • **Sponsorship of vertiport master plan studies and environmental assessments** • **Obtaining private financing if Federal and/or state grants are not available** • **Undertaking property acquisition, vertiport design, and construction**

NOTE: Issues dealing directly with infrastructure issues are shown in bold

Figure D6.0-1 Agency Responsibilities for CTR Passenger Transportation System Development (1 of 2)

Agency	Responsibilities
Industry	• Continuing the certification and development of CTR • **Sponsoring and/or supporting a CTR demo program** • Finalizing CTR configuration, performance and costs, and commit to production • Providing information and educating policy makers on the value of CTR
Operators	• Defining specific data/performance needs to reach CTR purchase decision • **Participation in CTR demo programs** • **Purchase or lease of CTRs for scheduled passenger/cargo service starting with high-density markets** • **Integration of CTRs into local/regional systems and hub operations and active promotion of CTR as part of regional/national networks**

NOTE: Issues dealing directly with infrastructure issues are shown in bold

Figure D6.0-1 Agency Responsibilities for CTR Passenger Transportation System Development (2 of 2)

D7.0 Conclusions

Based on the review and analysis of the Infrastructure Subcommittee, it can be concluded that:

1. A network of vertiports in key locations is critical to the economic viability of a civil tiltrotor (CTR) system. Community acceptance is the single most critical issue in developing off-airport, or vertiport, transportation infrastructure. Essentials for promoting community acceptance are:

(a) Noise reduction to minimize environmental impact and to lower land-use requirements.

(b) Overall safety of CTR passenger operations and the perception of the community at large that these operations are indeed safe.

(c) Public benefits such as improved transportation, increased access, jobs, tax revenues, etc.

2. Creating a successful scheduled passenger service CTR transportation system will require a substantial investment in infrastructure located away from conventional airports near major passenger demand points. While some Airport Improvement Program (AIP) or passenger facility charges (PFC) funding may be available, it is expected that the bulk of the construction funding may have to come from private capital markets and that financial feasibility will have to be demonstrated. Public ownership is expected for vertiports that support air carrier operations.

3. Under the present law, vertiports are eligible for funding under the AIP/PFC as well as other sources. However, in the current atmosphere of federal budget constraints and competition for those funds, it is uncertain whether AIP grants are likely to be available for vertiport acquisition, construction, and implementation.

4. The estimated cost for implementing the first 6 landing facilities in the start-up Phase 1 CTR infrastructure is approximately $67.5 million. The approximately 22 additional Phase 2 landing facilities are estimated to cost $599 million. Public/private partnership costs are estimated at approximately $9.4 million for system planning and decision coordination. This total cost of $676 million is for a program of approximately 10 years of planning, design, and construction. These costs do not include noise or environmental mitigation measures which are site specific and extremely difficult to estimate.

5. Vertiports should be located near major passenger demand centers with full consideration of intermodal transportation capabilities. This is key to maximizing the use of the CTR and fulfilling its role in reducing the overall national transportation congestion.

6. Vertiports for scheduled air carrier operations need much less land than conventional airports. To provide the capacity needed to handle the number of passengers required to make a scheduled air carrier system feasible, a typical ground-level vertiport will require approximately 20 to 30 acres. Elevated/multilevel facilities will to require approximately 10 to 20 acres. In order to mitigate noise impacts, a vertiport should be located where the surrounding area has stable compatible land uses such as rivers, lakes, industrial parks, rail yards, freeways, flood plains, etc. Some regulation, such as zoning or restrictive easements, may be required to preserve the stability of this compatible land use pattern. The size of this surrounding area will depend on the nature of the adjacent land use. Industrial and business land uses are normally compatible with noise levels below DNL 75 dB and DNL 70 dB respectively. Residen-

tial uses are normally compatible with noise levels below DNL 65 dB. The size of the noise exposure contours are shown in figure D7.0-1.

Noise Level	Contour Area (approximate)
DNL 75 dB	12 acres
DNL 70 dB	44 acres
DNL 65 dB	119 acres

Figure D7.0-1 Noise Exposure Contours

7. A demonstration of the flight characteristics and environmental impact in selected cities of a representative CTR is essential in evaluating whether the public and potential operators will accept and support this new technology.

8. Satellite-based navigation and automatic dependent surveillance (ADS) are expected to enhance safety of the required air infrastructure and to maximize CTR operational advantages.

9. The success of the CTR depends heavily on the capability and the willingness of the Federal Aviation Administration (FAA) to provide air traffic control (ATC) services in ways that allow the aircraft to operate efficiently. With the advent of global positioning system (GPS) and ADS, the ATC system will have the capability to handle CTR without causing significant delay to the CTR or to other aircraft. This is the case in both the en route and terminal areas.

10. Vertiports will require specific design criteria. The FAA Advisory Circular "Vertiport Design" needs to be revised to reflect advances in research and development (R&D) and the growing understanding of CTR capabilities.

11. Vertiports designed for CTR scheduled passenger service may accommodate current and advanced technology helicopters.

12. Vertiport studies have been done on individual sites. However, the integrated studies of area networks have not yet been accomplished.

13. Achieving CTR system and infrastructure development will require the cooperation and coordination of diverse institutional elements, where no one party has total jurisdiction, control, or the decision making power to implement, direct, or mandate the program unilaterally.

D8.0 Recommendations

In order for government and industry to make the many decisions that would be necessary to proceed, the Infrastructure Subcommittee makes the following recommendations:

1. A public/private partnership of Federal, state, regional, local governments, and transportation authorities, plus applicable industry and private interests should be established to evaluate the economic, political, and environmental feasibility of a system of civil tiltrotor (CTR) landing facilities at specific locations in the Northeast Corridor.

2. A more detailed analysis should be conducted to determine the availability and financial feasibility of specific vertiport sites in a network. Such studies should be conducted jointly with responsible parties from the various states and metropolitan areas.

3. Industry should continue to make every effort to enhance CTR safety, passenger comfort, and minimize CTR internal and external noise through stringent design requirements and operational procedures that may require design trade-offs that heretofore may not have been considered cost effective. Accomplishment of this task is considered essential to promoting public acceptance.

4. Vertiports should be considered in the local and metropolitan transportation facility plans and in urban/community development plans, as part of the comprehensive, continuing, and collaborative process.

5. A demonstration, in selected cities, of the flight characteristics and environmental impact of a representative CTR, should be funded to assist in determining whether the public and potential operators will accept and support this new technology.

6. Revision of the Advisory Circular (AC) "Vertiport Design" should address:

- Land-use planning in vertiport environs.
- Capacity requirements.
- Airspace requirements for low-visibility global positioning system (GPS) instrument procedures.
- Criteria based on the results of recent research and development (R&D) including:
  - Capacity.
  - Lighting and marking.
  - Touchdown lift-off (TLOF) surfaces instrument flight rules (IFR) separation.
  - Separations standards for TLOFs/final approach and takeoff (FATO) areas/ taxiways.
  - Rotorwash/wake vortices.

7. The Federal Aviation Administration (FAA) needs to develop guidelines for terminal route design to support CTR operation to vertiports in urban areas. The FAA needs to develop guidelines for implementing and designing airspace at vertiports. This is particularly important when the facilities lie under existing controlled airspace. The FAA also needs to develop guidelines for assessing impacts on local and regional airspace if controlled airspace is located around vertiports.

8. The FAA needs to develop terminal instrument procedures (TERPS) to support CTR operations at vertiports. This should include missed approach procedures and Category 2 and Category 3 operations. This work should be completed by the year 2000 to support subsequent vertiport planning, design, and implementation.

9. The Code of Federal Regulations, 14CFR77, "Objects Affecting Navigable Airspace," should be revised to address vertiport airspace issues.

10. The FAA needs to develop establishment criteria for air traffic control (ATC) towers appropriate for vertiports.

11. Additional research must be conducted to evaluate the potential wake vortex/rotorwash hazards that CTR aircraft might create, particularly for small helicopters, as well as to define operational procedures to alleviate these hazards.

12. The following R&D needs to be completed:

- CTR design to minimize external noise
- 14CFR77 for vertiports
- Designing and implementing airspace around vertiports
- ATC procedures
- Vertiport ATC tower establishment criteria
- Aircraft separation standards on approach to vertiports
- TERPS
- Update vertiport design ACs
  - — Land-use planning
  - — Capacity
  - — Lighting and marking
  - — TLOF IFR separation
  - — Separations standards for TLOFs/FATOs/taxiways
- Rotorwash/wake vortices

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D10.0 Airport Authority Letters

THE PORT AUTHORITY OF NY & NJ

AVIATION DEPARTMENT

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July 17, 1995

Mr. George Howard
President
Airports Council International
Suite 200
1220 19th St. NW
Washington, DC 20036

Dear Mr. Howard:

The Port Authority of New York and New Jersey remains encouraged by the potential of the Civil Tiltrotor (CTR) to ease airport congestion.

A civil transport version of the V-22 Osprey, combining helicopter point-to-point service with turboprop speed and comfort, could provide a quantum jump in system capacity. Operating independent of established airports and airways, a civil tiltrotor could transport passengers directly between demand centers. It is significant to note that at the three Port Authority airports, 45% of the departures deliver 20% of the passengers to destinations or first stops within 300 nautical miles, a distance well within the maximum effective range of a fully loaded V-22 Osprey. Displacing even a small fraction of the short haul traffic from runways to Port Authority operated vertiports could dramatically reduce delays at our capacity constrained airports.

The Port Authority fully recognizes that vertiport location is integral to the success of a CTR transportation system. In fact, in 1992, we completed a site selection study that identified a midtown, west side location as optimum. The potential site was chosen based on several factors such as: proximity to demand, community noise exposure, airspace, and intermodal transportation connections. While we intend to proceed with appropriate, follow-on planning activities, we reiterate our position that the Port Authority will work to provide necessary vertiport(s) when:

(1.) There exists a substantial passenger market that cannot be served efficiently at our existing airports/heliports;

(2.) CTR or other advanced VTOL design is proven safe, efficient and environmentally friendly;

(3.) Private sector investment occurs, i.e. CTR aircraft orders by reputable air carriers.

In our view, start-up CTR service in the NY area will likely be accommodated by existing heliport facilities, with modifications/upgrades as needed. As the market matures, we envision the construction of more elaborate, dedicated vertiport(s). We recognize that a throttled air transportation system can significantly impede economic growth. However, we must also acknowledge the immense political, environmental, social and financial challenges associated with a capital project of this magnitude within the urban core.

THE PORT AUTHORITY OF NY & NJ

Mr. George Howard -2- July 17, 1995

In closing, be assured that the Port Authority will continue to participate in the US DOT Civil Tiltrotor Development Advisory Committee and work with our industry partners to fully exploit the potential benefits of VTOL technology.

Sincerely,

Alfred J. Graser
General Manager
Aviation Technical Services Division

cc: Honorable Frank Kruesi
Assistant Secretary for Domestic Policy, US DOT

METROPOLITAN WASHINGTON AIRPORTS AUTHORITY

Washington National Airport ✈ Washington, DC 20001–4901

OCT 2 3 1995

Mr. George Howard
President
Airports Council International-North America
1775 K Street, N.W., Suite 500
Washington, D.C. 20006

Dear ~~Mr. Howard~~: George

As you requested in your letter of May 2, 1995, the Metropolitan Washington Airports Authority (Authority) staff has reviewed the key assumptions and analysis contained in the Draft Report (Report) of FAA's Economics Subcommittee of the Civil Tiltrotor Development Advisory Committee. The Authority staff's detailed comments are enclosed.

In summary, the subject of a public-use heliport/vertiport for the Washington metropolitan area has a long history and many of the comments reflect the work and conclusions of numerous studies that have been performed over three decades. The comments indicate that, despite many past studies, the likelihood of establishing downtown or suburban facilities as envisioned in the Report seems remote. The more likely scenario for siting vertiport facilities, particularly in the start-up period of tiltrotor service, would be the use of existing airport facilities.

If the Authority can be of any further assistance to the ACI or FAA in this matter, please feel free to call on us.

Sincerely,

James A. Wilding
General Manager

Enclosure

JAW:elc

COMMENTS ON THE CIVIL TILTROTOR ECONOMIC REPORT

BACKGROUND

There is a thirty year history of efforts to establish a public use heliport/vertiport in the Washington, D.C. area. The most recent effort (1992) by the Metropolitan Washington Council of Governments (MWCOG) explicitly considered the tiltrotor aircraft and broadened the study area to include suburban sites. All studies of the subject have concluded that the center of demand is the downtown business district—the area around 17th and K Streets. As sites become more distant from this location, demand drops sharply.

Due to the obvious security related restrictions on the airspace around the downtown area, absence of vacant land on which to build a new facility, and opposition from existing building owners and the local government from putting a heliport on top of an existing building, everyone has concluded that a heliport/vertiport will never be constructed or operated in the downtown area. Most studies have concluded that the nearest available site to the downtown area is Washington National Airport.

One recent (1993) event is worth noting. A private firm (Air Pegasus), which operates heliports, proposed to convert the private use heliport located at the Steuart Petroleum facility in the Southeast to a public use facility. While not ideally located, the site is near the Capitol, already is used by private helicopters, has sufficient area to accommodate (at grade) related support facilities, is on an established airspace route for helicopters, and would have minimal environmental impact of residential areas. Air Pegasus proposed a long-term plan to develop the property from a private use heliport into a public use vertiport with passenger terminal facilities. The Aviation Subcommittee of MWCOG supported the concept as, realistically, being the best opportunity to develop such a facility. The Subcommittee urged the representative from the District to pursue the matter with District officials. The District indicated that it was opposed to the concept. As a result of the District's decision, the Aviation Subcommittee has removed the topic of heliports/vertiports from its list of on-going studies to be periodically updated.

CIVIL TILTROTOR DEVELOPMENT—ECONOMICS SUBCOMMITTEE REPORT

The FAA's on-going study (Study) of the viability of a civilian version of a tiltrotor aircraft has many dimensions, only one of which is relates to the economic viability. However, it is clear that the economics must be right if there is ever to be a successful civilian version of the tiltrotor aircraft. While the subject report deals with many aspects of the economic

picture—manufacturing, market demand, operating costs, infrastructure costs, delay reductions—it is apparent that all of the economic issues come back to the Northeast Corridor which is considered to be the largest potential market for commercial service. For example, if the manufacturing levels are to be achieved to produce the necessary economies of scale to make the aircraft capital costs manageable, there has to be an operator(s) in the Northeast Corridor flying a fairly large fleet of aircraft. Without a large Northeast Corridor fleet, manufacturing economies of scale are not realized, operators in weaker markets face higher aircraft acquisition costs, etc. While the Metropolitan Washington Airports Authority (Authority) cannot speak to manufacturing and operating cost issues, the Authority does offer the following comments related to the economic and other aspects of vertiport development in the Washington, D.C. area.

Non-Airport Vertiport Development

The Study indicates that a vertiport suitable for civilian tiltrotor (CTR) operation will require 10 to 30 acres. The smaller site area for vertiports in congested downtown locations is achieved through the use of structured parking and other not-at-grade facilities to minimize land acquisition costs. In addition to the land area dedicated to vertiport use, ±120 acres would be subject to 65 LDN aircraft related noise.[1] The Study estimates that the Washington metropolitan area will require one downtown site and one suburban site. The estimated (1993) capital costs for developing these sites are $33.4 and $25.0 million, respectively.

While the study is not specific as to the locations of the Washington sites, it is reasonable to assume that the "downtown" site would want to be as close to the Mall as possible. From the 1992 MWCOG study the "suburban" site would have to be Tysons Corner or Shady Grove as these are the only two areas within the populated metropolitan area zoned to permit such development.

Developing even a ten acre site anywhere near the Mall, business center, or the Capitol is very unlikely. By definition, the P-56 Restricted Airspace would prohibit development in this area. Recent events suggest that security concerns will only increase restrictions on both air and ground movements in this area. Even without the security concerns, the ability to carve out a ten acre site in one of the Nation's most highly visible and regulated land-use areas is problematic. When the extent of the noise impacted area (±120 acres) is considered, the prospects of a truly "downtown" vertiport seems improbable. As indicated above, the only practical site within the District's boundaries in terms of size, own- and adjacent land-use, airspace, and demand potential would have been the Steuart Petroleum site. Development of a vertiport in this area was recommended by the MWCOG study and supported by the Aviation Subcommittee. This concept was proposed to and rejected by the District of Columbia.

[1]The ±120 acres assumes that substantial improvements can be made in reducing the noise signature of the existing (military) tiltrotor aircraft. Without such a reduction the land area impacted by noise would be ±250 acres.

- 2 -

In the suburban area, the only two sites are Tysons Corner in Virginia and Shady Grove in Maryland. While both areas have the necessary zoning to permit development of a vertiport, any proposal for development would likely be opposed by local residents. Of the two suburban sites, only officials from Montgomery County (Shady Grove) have expressed an interest in such a development. Unfortunately, the Shady Grove site is the most distant from the demand centers and has the weakest market potential.

For either a downtown or suburban site, a significant issue would likely be the loss of local property tax revenue. By definition, the vertiport site wants to be, perhaps has to be, in a prime business area. Transfer of 10 to 30 acres of such land from private (taxable) use to a public airport operator (non-taxable) would have an impact of local property tax revenues.

In terms of the study's estimated costs for developing a downtown site ($33.4 million) or a suburban site ($25.0 million), both figures appear to be much too low. Without knowing the extent of land and avigational easement purchases, the size and nature of airfield, terminal, and landside facilities, it is impossible to comment in detail. However, given the recent construction/cost experiences at DCA, it seems questionable the facility envisioned could be constructed for the estimated amounts.[2] Some typical unit costs for DCA facilities are $574 per sq. ft. for a ground level commuter terminal, $106 per sq. yd. for apron/taxiway/runway, and $13,000 per space for structured parking. In addition to these costs would be the navigational aids, approach, runway, and taxiway lighting, ATC tower and equipment, ARFF station and equipment, fueling facilities and access/egress roadways.

One economic aspect that was not adequately addressed in the Study was the mechanics of financing the capital cost, at any level, for the development of the vertiports. As a practical matter, the vertiport operator would have to be an existing airport operator. For Washington, D.C., the Authority would be the developer/operator of the two vertiports. Using the Study's estimates, the Authority would have to finance $58.4 million in capital costs. This would be a very risky investment since, by definition, this investment would have to be in place before the service begins. In fact, the planning, design, and construction would have to begin without there being an operating airline. It is unlikely that the airlines at the existing airports would be willing to support (guarantee) this type of an investment which means that the investment would have to come from net operating revenues from non-airline cost centers. Even with optimistic assumptions regarding FAA grants for eligible projects, the Authority would be risking many millions of dollars on a very specialized facility that has no alternative use.

Airport Vertiport Development

[2]The Study envisions the tiltrotor service catering to the business traveler willing to pay a premium for convenience and time savings. The vertiport "terminal area" is described as offering a full range of terminal services including rental cars and terminal concessions.

An alternative to developing separate vertiport facilities would be to use existing airports. Most previous studies have concluded that DCA is the nearest "downtown" site for a heliport/vertiport. As the Study recognizes, DCA is a slot controlled high density rule (HDR) airport. Under current regulations, a tiltrotor aircraft, as described in the Study, would be required to use a commuter slot for an operation at DCA. Under such a scenario, tiltrotor aircraft would be treated the same as any other commuter aircraft and the tiltrotor operator would be able to use existing apron, terminal, concession, parking, etc. There would be no capital cost for this type of operation.

In a meeting with the Study authors, it was suggested that, because of the tiltrotor flight characteristics, the aircraft could operate outside of the normal terminal and en route airspace routes and, thus, not require the use of a slot. Such a determination is not within the discretion of the Authority and would have to be made by the FAA Administrator. However, there is precedent for such a determination in that two slots per hour were added to the original commuter limit of eleven for the use of STOL aircraft (e.g., DH7s). Again, the FAA Administrator would have to determine that the number of commuter slots can be increased with the increase allocated to tiltrotor operations. Under this scenario of increased commuter operations, there may be a need to increase the size of some facilities to accommodate the increased number of parked aircraft, passengers, and vehicles. In terms of total activity levels, these increases would be minor and well within the ability of the Authority to develop facilities to meet the increased demand.

Similar possibilities exist for the suburban vertiport sites. Washington Dulles International Airport is available, without slot limitations, as a Northern Virginia site. While the Authority cannot speak for other jurisdictions, it seems feasible for tiltrotor aircraft to operate from Montgomery County Airpark.

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Civil Tiltrotor Development Advisory Committee

Report of the Economics Subcommittee

CTRDAC Economics Subcommittee

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Chair, Economics Subcommittee
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Philadelphia International Airport

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CTRDAC Economics Subcommittee Report

CTRDAC Economics Subcommittee Report

Executive Summary

Introduction

The mission of the Civil Tiltrotor Development Advisory Committee (CTRDAC) is to present to Congress the best judgement of the Committee regarding the technical feasibility and economic viability of tiltrotor transportation. The Economics Subcommittee of the CTRDAC was tasked to address the economic viability of civil tiltrotor (CTR), including demand for and profitability of particular proposed tiltrotor services. The Economics Subcommittee also was tasked to address broad national issues including: public support for vehicle development; comparison of public benefits and costs; impact on existing services; employment effects; export potential; and international competition.

The XV-3 and XV-15 tiltrotor research aircraft programs were directly responsible for the design of the military V-22 tiltrotor multi-mission aircraft now in the final stages of flight testing and scheduled for limited production later this decade. Although the V-22 has great potential to successfully perform a variety of military missions, the requirement to operate from a ship and to meet various military standards make it too slow and heavy to operate economically as a passenger carrying commuter aircraft. It is also too noisy to operate out of community vertiports. To compete in the civil market, new technology needs to be developed. This includes a low-noise proprotor design and operation, an advanced tiltrotor cockpit to enable steep approaches to congested terminal areas, and additional contingency engine power.

The development of this technology could also be used to design a range of civil tiltrotors from corporate or executive aircraft with 8 to 15 seats, up to a medium-sized commuter passenger aircraft with up to 75 seats with a range of up to 600 nautical miles. Previous studies suggest that the largest market would be for a 40-passenger version with speeds of 350 to 400 miles per hour.

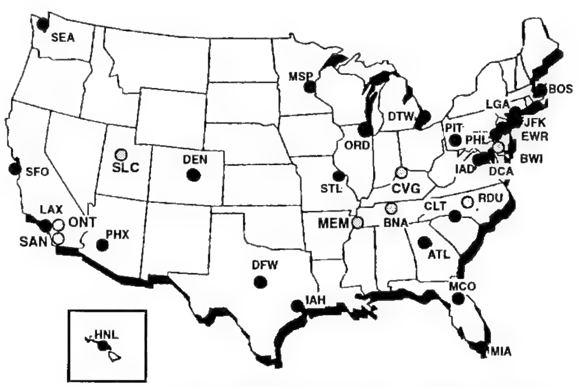
Background

A major irony of modern jetliner transportation is that much of the total travel time is spent on the ground. For journeys under 700 miles, passengers typically spend over half of their total travel time on roads accessing or egressing an airport, at the airport terminal checking-in or passing through security, in the aircraft taxiing around the airport, and/or otherwise waiting in a queue for any of the above.

Since the invention of the helicopter, transportation visionaries have thought that one day vertical flight would provide the next step in the evolution of transportation, providing near doorstep-to-doorstep carriage. Unfortunately, helicopters have not evolved radically from the time of their invention to modern times, unlike a Boeing 747 of today which bears only a small resemblance in form, function, and comfort to the first airplane of the Wright brothers. In general terms, helicopters remain small compared to a modern jet aircraft, and are perceived by much of the traveling public to be uncomfortable compared to a modern turboprop. In absolute terms, existing helicopters are limited to forward speeds of less than 200 miles per hour which is considerably less than the speed projected for CTR. Helicopters also cost considerably more to operate per seat mile than jets or turboprops.

CTR aircraft offer the potential to develop new types of intercity passenger transportation markets. Because of the development of the V-22, the U.S. is at the forefront of this technology, with a substantial lead-time advantage over foreign countries in the ability to apply this technology in civil aircraft. As a result, there are potentially large benefits to the U.S. economy if the market for CTR vehicles can be developed in a timely manner.

The difficulty in expanding existing airports will lead to greater delays in the future. According to the Federal Aviation Administration (FAA) 1994 Aviation Capacity Enhancement Plan, 23 airports in 1993 each exceeded 20,000 hours of annual aircraft flight delays. Assuming no improvements in airport capacity are made, nine additional airports are forecast to each exceed 20,000 hours of aircraft flight delays by 2003 (figure E1).



- **Congested airports 1993 (actual)**
- **Additional congested airports 2003 (projected)**

Source: FAA Office of Policy and Plans
Note: 1) assumes no capacity improvements
2) Denver 1993 congestion alleviated by opening of new airport

Figure E1 Airport Delays

A particular attraction of the tiltrotor concept is that it would not require the full use of an airport's instrument flight rules (IFR) capacity or its landing slots. The aviation community perceives CTR as a means to alleviate congestion in high-density markets because CTRs can emulate a helicopter in vertical takeoff and landing, providing the opportunity to remove aircraft from regular takeoff and landing queues. Because CTRs could fly at a variety of altitudes up to 32,000 feet, CTRs would not add substantially to airspace congestion in the few existing crowded en-route corridors. Proponents of the CTR believe that they have the answer to what the helicopter visionaries sought. The CTR, which can take off and land like a helicopter and fly with the speed and comfort of a modern turboprop aircraft, holds the promise for a major step forward in providing demand-center to demand-center transportation. By flying to and from vertiports located close to the ultimate origin and destination of passengers, the CTR can substantially reduce travel times, creating a more valuable transportation service.

Developing a totally new short-haul transportation system requires more than action by aircraft manufacturers alone. Because of the need for new infrastructure, it will require a cooperative effort of aircraft manufacturers, airlines, and governments.

Study Approach

One of the questions that needs to be answered if CTR development is to go forward, is that of CTR viability. This analysis requires looking at the commercial, economic, and social viability aspects of CTR technology investments. This assessment must take into account all of the potential benefits and costs that could arise from the development of CTR. However, the underlying question that always needs to be discussed when looking at viability is "viability to whom?". Through this method it is possible to assess the impact of developing CTR as a new aeronautics technology.

CTR will be a commercially viable product if the innovating firm (i.e., manufacturer) can earn a return on its investment that is large enough to allow recovery of all production and development costs, plus a normal profit. This also requires public acceptance of CTR and commercially viable operation of CTR by airlines. For an operator, this means earning a return sufficient to offset the acquisition and operating costs of a CTR, plus a normal profit. Commercial viability can be analyzed by calculating the discounted cash flows for

CTR based on appropriate private discount rates for the manufacturers and operators. The net present value (NPV) of the cash flows to the firm are positive when they are discounted at the firm's opportunity cost of capital.

CTR may by economically viable, even if not commercially viable, if CTR produces economic benefits through its unique operating characteristics and these benefits can be "transferred" between various groups involved with CTR. Benefits could be transferred either in the form of cash or in-kind benefit exchange. For example, introduction of CTR at an existing airport could increase airport capacity without the need to build expensive new runways that CTR does not require. For congested airports contemplating expansion, the benefits could be significant, both to the airport operator (i.e., funding expansion) as well as to the airlines (e.g., reduced delays, avoided cost of expansion). Some of these benefits could be passed back to CTR operators in the form of reduced landing fees.

Finally, CTR may be socially viable, even if not commercially or economically viable. CTR might produce an NPV of social benefits in excess of social costs when discounted at an appropriate social discount rate. For example, CTR introduction could result in some reduction in fixed-wing aircraft operations at airports that could reduce delays for all air passengers. Social viability differs from economic viability in that the benefits of the former are typically less easily quantified and more difficult to transfer among the stakeholders, including CTR manufacturers, airlines, airports, and nearby airport residents.

The viability of CTR was assessed by performing market analyses for various economic and transportation scenarios involving introduction of scheduled CTR passenger service. Four potential market areas were considered: Northeast, Midwest, Southwest, and West Coast. For each scenario, diversion estimates were made from each of the existing modes (i.e., air, auto, and rail) and for business and non-business trip purposes. The air mode is separated into jet and turboprop as well as origin-to-destination and transfer market segments.

The short-haul system analyzed assumed that the 40-passenger CTR (figure E2) would be suited to three primary commercial markets (figure E3):

- *Line-Haul Service*

Vertiport-to-vertiport operation between urban/suburban centers characterized by significant passenger demand.

- *Feeder Service*

From regional airports to urban/suburban demand center vertiports.

- *Transfer Service*

From a demand center vertiport to a vertiport located at a congested hub airport.

Market analyses consist of iteratively applying sub-models to develop estimates of:

- Travel in the base year (1992) by existing modes.
- Travel projections in future years (2010 to 2030).
- Modal characteristics in future years (travel time, fares, frequency, etc.).
- Diversions to the proposed CTR service.
- Costs of acquiring CTR aircraft and vertiports.
- Costs of operating the CTR enterprise.
- Social impacts related to introduction of CTR service (e.g., airport congestion, energy and emissions).
- Financial summary measurements (e.g., estimates of revenues and costs in future years).

CTR fares were set at levels sufficient for CTR operators to achieve a reasonable profit in each market served. In addition, the number of vertiports and the frequency of CTR operations were adjusted to be consistent with forecast CTR traffic volumes.

The main market demand model used a three-step process based on the concept that the introduction of a new travel option such as CTR will result

Performance Summary	
Maximum vertical takeoff gross weight	43,150 lb at 2,000 feet/ISA +20 degrees C at sea level/standard day
Operating empty weight	28,623 lb
Design range	600 nm with full passenger load and IFR fuel reserves
Maximum cruise speed	350 knots at 25,000 ft
Best range airspeed	315 knots at 30,000 ft
Service ceiling	32,000 ft
Maximum range	>1,000 nm with IFR reserves
Installed Engine Characteristics	
Engine number and type	Two IHPTET turboshaft
Maximum takeoff rating	7,260 SHP/engine at sea level/standard
30 - second contingency rating	8,820 SHP/engine at sea level/standard 7,800 SHP/engine at 2,000 ft/ISA +20 degrees C
Physical Characteristics	
Rotor diameter (each)	36.3 ft
Fuselage length	62.4 ft
Height	23.6 ft
Width (rotors turning)	86.2 ft
Number of cockpit crew seats	2
Number of passenger seats	40 plus 1 attendant
Installed horsepower	7,260 shaft horsepower/engine at sea level/standard maximum static

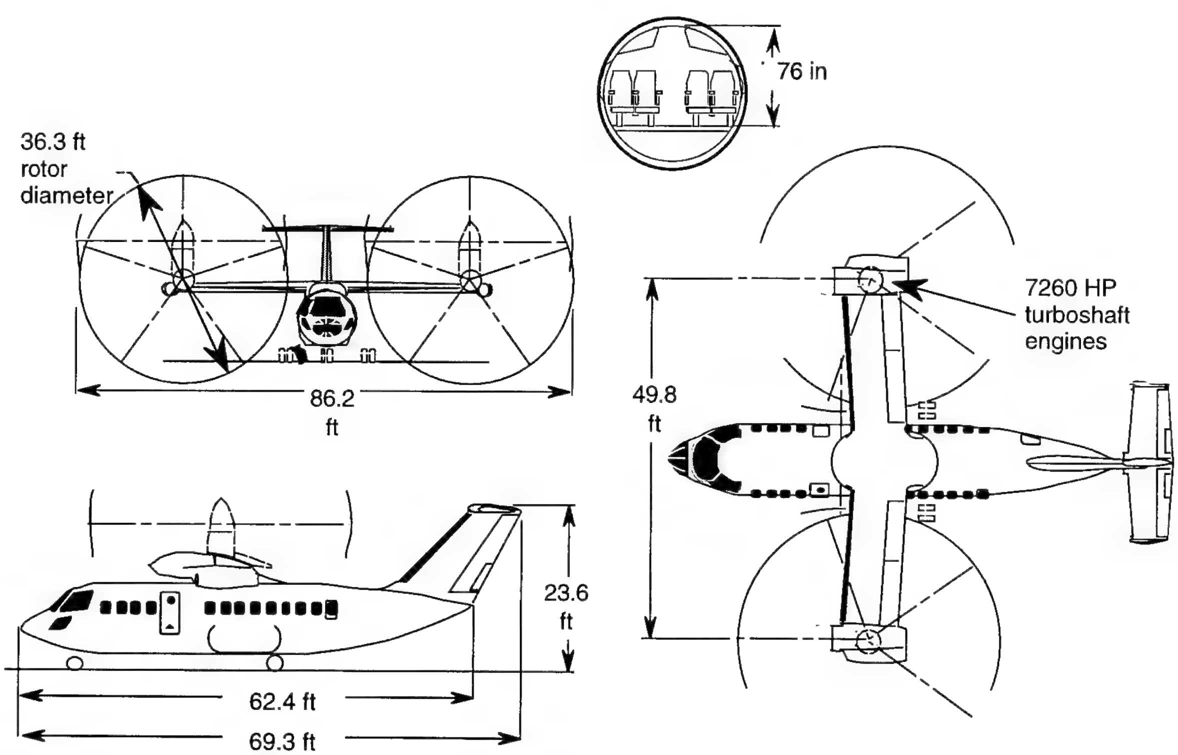


Figure E2 40-Passenger CTR

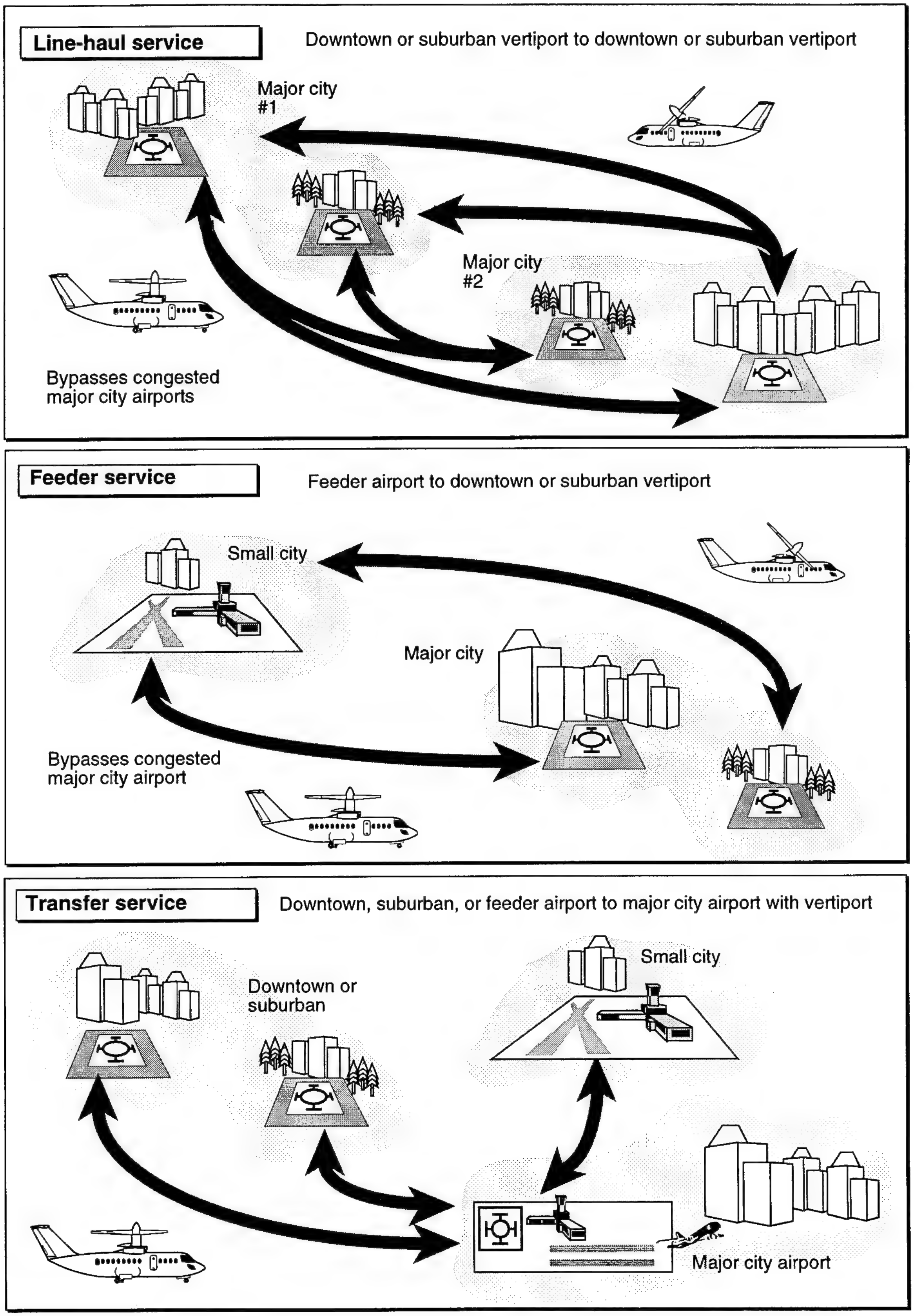


Figure E3 CTR Commercial Markets

in individuals reconsidering the attributes of all travel options, and then selecting one which best meets their trip purpose. The decision as to which mode to use is driven by how the individual values his/her time (versus trip purpose) and the effect of individual preferences for the available modes. The set of mode choice or diversion models used was based on research conducted on customer preferences in a number of U.S. and Canadian corridors. The models were refined over time as more data were collected from each of the corridor studies. Further refinements to the models were made to assess the market feasibility of maglev and other high-speed ground transportation alternatives. For the purpose of this study, revisions were made to the models, particularly to the mode bias coefficient, to account for individual preferences between conventional travel choices and CTR.

CTRs were assumed to be regarded by travelers as equal to turboprops in amenities, comfort, and safety. This implies that the mode preference for CTR versus turboprop aircraft is zero. Mode preference is defined as the amount a traveler would prefer one mode over another if their travel time, cost and frequency were equal. Travelers were assumed to have a mode preference for jet travel over both CTR and turboprop. This preference is quantified at approximately $15 to $18. The value of the mode preference constant increases with trip distance, so that at 500 miles the preference is one-third higher than at 200 miles.

Various other models contributed to the analyses. A financial performance model was used to estimate passenger demand, service characteristics, and costs of CTR operations in specific markets. A vertiport cost model was used to estimate vertiport construction and operating costs as derived from elemental design criteria for a set of generalized vertiport layouts which might be located in city centers and suburban locations. Finally, an energy and emissions model was used to measure these impacts based on changes in modal demand and access/egress travel times, modal energy intensities, and emission rates. Dollar valuations for the emissions were calculated using a methodology developed by Argonne National Laboratory.

The financial model consisted of four cash flow modules, including Government/industry research and development, manufacturing, operations, and delay plus environmental effects. The Government/industry research and development cash flow is assumed to begin in 1994 and span 10 years with total expenditures of approximately $600 million. A manufacturer cash flow model was developed with private development costs assumed to begin in 2003 and extending for 4 to 5 years. The first aircraft deliveries were assumed to be made in 2007 and continue for 15 years.

Once deliveries begin, an operations cash flow was developed from the Volpe Center analysis which provided base activity projections for the years 2010 through 2030. For each market area, operations were assumed to begin in 2007 or later, coinciding with the first CTR deliveries, and ramp up to the demand projections in 3 to 4 years. For years after 2010, an annual growth rate in operations consistent with demand projections for later out-years was assumed. The cash flows were established for a 20-year period.

Key Findings

The following represent the major findings of the CTRDAC Economics Subcommittee:

- CTR service instituted in the first or second decade of the next century could attract sizable ridership in many domestic markets (figure E4). CTR service is more likely to be financially viable in the Northeast and some Midwest markets due to

Corridor	Percent Diverted From Air	Typical Fare Premium (percent)	Number of CTR Enplanements
Northeast	20	45	5.9 million
Midwest	12	15 to 125	3.5 million
West Coast	4	135	1.5 million
Southwest	6	130	0.3 million
Overall	**11**		**11.2 million**

Figure E4 CTR Ridership

higher prevailing airfares in these markets. CTR service in markets where existing airfares are low, such as the West Coast and Southwest, would be less financially viable.

- In most markets, CTR fares will likely need to be substantially higher than prevailing conventional airfares to cover higher projected CTR per-passenger costs due to higher initial acquisition and operating costs. However, because CTR would usually offer lower overall travel times, including advantages in access/egress time, it has a competitive total trip time and cost for some passengers. This would result in CTRs capturing a reasonable share of the market in certain corridors (figure E5).

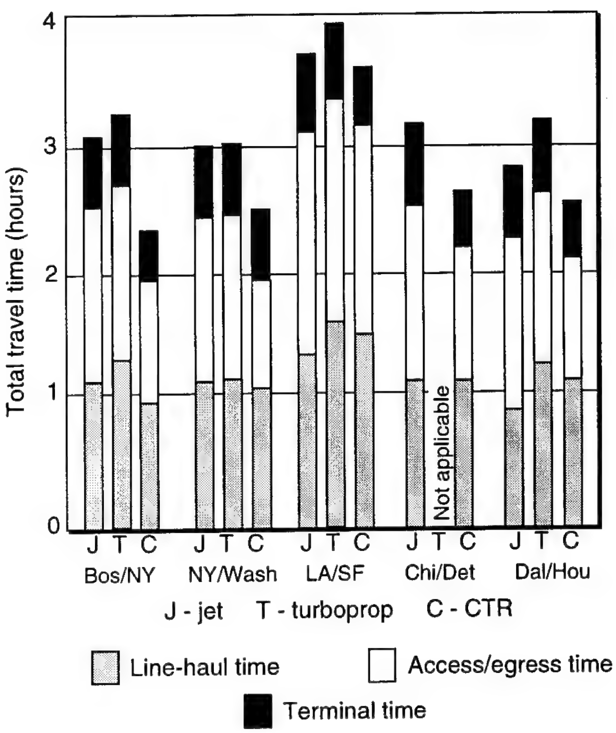


Figure E5 CTR Travel Times

- The CTR can produce significant social benefits (figure E6) when used to alleviate congestion at capacity-constrained airports. However, only a small portion of these benefits accrue to an airline operating CTRs. For this reason, this type of benefit may not be a sufficient incentive for airlines to acquire CTRs. Offsetting these benefits, in part, are the increased fuel consumption and engine emissions of the CTR compared to conventional airplanes and other intercity transportation modes. In addition, there may be other strategies which could also alleviate congestion and reduce delays.

Category	Government-Private NPV (millions of $)	Societal NPV (millions of $)
Government/industry research and development	$(435)	$(435)
Industry vehicle production (discounted at 12 percent for private NPV and 7 percent for societal NPV)	$273	$900
Vehicle operations (discounted at 10 percent for private NPV and 7 percent for societal NPV)	$27	$175
Delay reduction	$1,230	$1,230
Infrastructure	0 *	0 *
Total	**N/A**	**$1,860**

* Self-financed from CTR operator fees and passenger ticket taxes and/or user fees.

Figure E6 CTR Societal Benefits

- The worldwide demand for 40-passenger CTRs is estimated to range from 1,160 to 1,600 vehicles in the year 2010, including more than 400 in the North American market (figure E7). This is

Market Region	Forecast Range
Four major U.S. corridor markets (note 1)	235 to 325
Other North American corridor markets (note 1)	150 to 200
Europe	300 to 400
Japan	300 to 400
Oceania	100 to 125
Total passenger CTRs	1,085 to 1,450
Other applications (note 2)	75 to 150
Total	**1,160 to 1,600**

Note 1: Vertiport-to-vertiport, plus feeder, plus transfer markets. Transfer market included in top end of the range
Note 2: Other worldwide applications for 40-seat aircraft include package express, corporate, search and rescue.

Figure E7 CTR Worldwide Demand in 2010

based on a projected selling price of $18.5 million per unit. A higher selling price could result in lower CTR demand.

• The ability of CTR to operate in close proximity to the true origins and destinations of air passengers is key to its commercial viability. The development of a low-noise rotor is an important prerequisite for community acceptance of vertiports and CTR operations.

• Successful CTR introduction depends on overcoming uncertainties and risks. The largest CTR passenger demand uncertainties involve air carrier and CTR fares and travel time, and the siting of vertiports (figure E8).

Variable	Change in Assumptions	Change in CTR Ridership
Conventional airfares	+15%	+17%
	-15%	-17%
Conventional air delay per operation	+20%	+9%
CTR fares	-10%	+45% to +80%
	-20%	+95% to +160%
	+20%	-45% to -70%
CTR initial price	+10%	-10%
	-10%	+10%
CTR line-haul travel time	+10%	-7%
	-10%	+14%
Vertiport locations	All less favorable	-31% to -33%

Figure E8 CTR Sensitivites

• Airplanes operate with well developed air traffic control (ATC) and airport infrastructure, and they are a known part of the transportation system. CTRs, on the other hand, require vehicle development and new types of infrastructure such as vertiports. As such, even though there may be substantial benefits to travelers and the nation as a whole from CTR introduction, the market may not adopt this technology in a timely manner without a coordinated public/private effort.

• The manufacturers have estimated a CTR selling price of $17 million to $20 million, based on substantial improvements in manufacturing economies. CTR manufacturing costs are also critical to its commercial viability. At a cost necessary to support a $18.5 million selling price, a CTR program would have a real rate of return on cash flow of 12 percent if approximately 500 units could be sold over 10 years. If more units were sold, the rate of return would be higher. Overall, the CTR production program would have an NPV of $273 million in 1995 if cash flows are discounted at 12 percent.

• Although the estimated demand for CTR aircraft seems sufficient to satisfy the minimum requirements of manufacturers to pursue CTR development activities, it is unlikely that a U.S. manufacturer would launch a CTR program without further development of the technology because of the technical and market risks involved. It is estimated that the research and development program would entail an expenditure of approximately $600 million over a 10-year period. This has a NPV of $435 million in 1995 when discounted at 7 percent.

• Operation of CTRs in the four U.S. corridors studied would provide operators with a real rate of return of approximately 11 percent at a CTR selling price of $18.5 million. This estimate is based on the operator revenue and cost relationships assumed in the market analysis. A higher rate of return can be achieved, but at the expense of higher CTR costs, fares, and lower ridership. Operator cash flows have a NPV of $27 million in 1995 when discounted at 10 percent.

• Vertiports can be self-financing. This depends greatly, however, on the assumptions made concerning the availability and applicability of Federal airport funding mechanisms, such as the Airport Improvement Program (AIP) and passenger facility charges (PFC). Given a reasonable range of funding scenarios, the level of self-financing attained in a typical year after completing construction of a 27-vertiport system was approximately in the plus or minus $10 million range.

• The NPV in 1995 of the social benefits (delay reduction) and social costs (increased emis-

sions) of CTR operations in the four corridors studied totals approximately $1.2 billion.

- Overall, when considering all private and social benefits and costs, and how they occur over time, the CTR program has an estimated real rate of return of as much as 15.5 percent.

- CTR research and development, production, operation, and environmental effects have a societal NPV of $1.9 billion in 1995 when discounted at 7 percent (figure E9). Manufacturer and operator NPVs are lower when using discount rates which reflect the risk premium they would place on CTR investments.

Category	Government-Private NPV (millions of $)	Societal NPV (millions of $)
Government/industry research and development	$(435)	$(435)
Industry vehicle production (discounted at 12 percent for private NPV and 7 percent for societal NPV)	$273	$900
Vehicle operations (discounted at 10 percent for private NPV and 7 percent for societal NPV)	$27	$175
Delay reduction	$1,230	$1,230
Infrastructure	0 *	0 *
Total	**N/A**	**$1,860**

* Self-financed from CTR operator fees and passenger ticket taxes and/or user fees.

Figure E9 CTR Net Present Values

Risks and Uncertainties

There are considerable risks and uncertainties inherent in evaluating the likely economic and social performance of any new transportation mode. The analysis evaluated the demand for CTR vehicles between the years 2010 and 2030. Start-up difficulties and risks were assumed to be manageable. In addition, the analysis assumes that base values can be achieved for a number of important parameters, most importantly the structure and performance of the airline industry in the future. The key uncertainties include the following:

- *Future Airfares*

The demand for CTR service is affected by the levels of future airfares.

- *Airline Competitive Response*

The way in which airlines react to the introduction of CTR services will also affect the commercial viability of CTR service, especially in the early years just after introduction.

- *Vertiport Siting*

The ability to locate vertiports close to ultimate passenger origin and destination points is a key to its competitive advantage over other modes.

- *Start-up Costs*

While the analysis in Chapter E10 of this technical supplement includes provisions for start-up costs, it was not possible to develop precise estimates of these costs.

- *Future Air Travel Demand*

The demand projections for future CTR service and the level of delay in the conventional air transportation system both depend on the growth rate in future air travel.

- *CTR Operational Efficiency*

There are no data based on service experience for the actual operating cost performance of CTRs.

- *CTR Production Costs*

There is only a limited history of manufacturing costs for tiltrotor vehicles.

- *ATC Accommodation*

The analysis assumes that CTRs can be accommodated on a non-interfering basis in the future ATC system.

- *Passenger Acceptance*

It is not known to what extent passengers will accept the use of CTR vehicles for scheduled commercial air transportation.

- *Perceptions of Safety*

There is no base of information with which to predict the passenger perception of CTR safety or how this will effect demand.

- *Risk Compounding*

CTR commercial success is vulnerable to failure due to risk compounding. "Success" requires that a large number of unknowns be resolved in favor of CTR while a negative resolution of only one or two unknowns could result in failure.

Many of the above risks have been examined in sensitivity analyses conducted as part of the CTR-DAC effort. Some of these risks are of a threshold nature that must be resolved satisfactorily for the successful introduction of CTRs into commercial service. Ultimately, some of these risks and uncertainties can only be resolved after introduction of CTR service.

Recommendations

The major recommendations of the Economics Subcommittee are that:

- A Government-supported research and development program for technical risk reduction focused on environmental and safety areas is needed. Industry cost sharing should be considered where appropriate. Milestones should be built into the program to redirect or terminate the program if intermediate results so warrant.

- Work should begin on site identification and preliminary planning for vertiports. This includes planning for modifications to existing facilities, including select airports and heliports, for start-up facilities, and for development planning of new vertiport facilities for a mature CTR network.

- An industry/Government partnership is needed for implementation of CTR. Numerous issues require simultaneous decisions. No one party can make all the necessary decisions and implement CTR alone because no one party controls all the resources CTR will require.

- A CTR network study involving manufacturers, the FAA, and local governments should be developed for one promising U.S. corridor. The study should include identifying specific vertiport sites to determine operational requirements and improve demand analysis. A zone-specific passenger origin/destination travel demand analysis should be performed incorporating travel time sensitivity. This analysis must use data comparable across metropolitan areas. Finally, the active cooperation of local planning bodies must be sought to acquire necessary input data for vertiport locations, CTR operations planning, and general issues related to community acceptance of CTR.

- The large potential of CTR for reducing transportation delays entitles CTR to consideration as an alternative to other ways of achieving the same benefits, such as expanding or building new airports, improving ATC, developing higher speed rail systems, expanding or building new highways, developing intelligent highway vehicle systems, or implementing demand management (i.e. congestion) pricing for existing transportation systems.

E1.0 Introduction

E1.1 CTRDAC Mission

The mission of the Civil Tiltrotor Development Advisory Committee (CTRDAC) is to present to Congress the best judgement of the Committee regarding the technical feasibility and economic viability of civil tiltrotor (CTR) transportation. The Economics Subcommittee of the CTRDAC was tasked with determining the economic viability of the CTR, including the demand for and profitability of specific proposed tiltrotor services, and the impact of CTR on broad national issues.

E1.2 Economics Subcommittee Tasks

The Economics Subcommittee was tasked to address Congressional requirements fundamental to the mission of the CTRDAC as well as additional supporting tasks as determined by the legislation creating CTRDAC, The Airport and Airway Safety, Capacity, Noise Improvement, and Intermodal Transportation Act of 1992 (PL 102-581). Congress required that the Committee:

- Determine the economic viability of developing a CTR aircraft and establishing the necessary infrastructure.
- Determine the benefits to the national economy and transportation system of CTR service.

Supporting tasks assigned to the Economic Subcommittee by the CTRDAC include to:

- Examine the economic viability of CTR service. Estimate the capital and operating costs of CTR service in a range of potential markets. Estimate the extent of markets where CTR would be profitable.
- Prepare the estimates of delay reduction where CTR is viable.
- Determine the public investment requirements for development of aircraft/infrastructure.
- Compare public benefits and costs of CTR service.
- Identify the impact of CTR on other air and surface modes, including connections to other modes of transportation.
- Estimate the net employment effects from CTR production and operation.
- Determine the export potential of CTR and its effect on international aerospace manufacturing competition.

E1.3 V-22 and CTR Technology Development

The XV-3 and XV-15 tiltrotor research aircraft programs were directly responsible for the design of the military V-22 tiltrotor multi-mission aircraft now in the final stages of flight testing and scheduled for limited production later this decade. Although the V-22 has great potential to successfully perform a variety of military missions, the requirement to operate from a ship and meet various military standards make it too slow and heavy to operate economically as a passenger carrying commuter aircraft. It is also too noisy to operate out of community vertiports. To compete in the civil market, new technology needs to be developed. This includes: low-noise proprotor design and operation; advanced tiltrotor cockpits to safely allow steep approaches to congested terminal areas; and additional contingency engine power. Technology requirements for a CTR vehicle are discussed in the Aircraft Subcommittee Report contained in this technical supplement.

The development of this technology also could be used to design a range of civil tiltrotors from corporate or executive aircraft with 8 to 15 seats up to a medium-sized commuter passenger aircraft with up to 75 seats with a range of up to 600 nautical miles. Previous studies suggest that the largest market would be for a 40-passenger version with speeds of 350 to 400 miles per hour (reference 1). In addition, introduction of CTRs into the marketplace will result in more rapid maturation of tiltrotor technology. In turn, this could result in tiltrotors of other sizes and configurations that could be of interest to the military for other missions.

E1.4 The CTR Vehicle

The Economics Subcommittee analyzed a 40-passenger CTR used for scheduled intercity passenger transportation in its market assessment. The 40-passenger CTR could serve three primary types of commercial markets:

- *Line-Haul Service*

Vertiport-to-vertiport operation between urban/suburban centers characterized by significant passenger demand.

- *Feeder Service*

From regional airports to urban/suburban demand center vertiports.

- *Transfer Service*

From a demand center vertiport to a vertiport located at a congested hub airport.

Examples of the urban area to urban area markets are the Northeast Corridor, the Dallas/Ft. Worth to Houston Corridor, between major cities in the Midwest, and the Los Angeles Basin to San Francisco Bay Area Corridor. Such markets contain strong flows of business travel and have frequent scheduled services provided by conventional fixed-wing aircraft. Furthermore, ground access to the major airports in these markets is already difficult, particularly during peak times of the day.

A CTR operating in feeder markets would connect airports in small cities currently served by smaller jet and turboprop airplanes with metropolitan vertiports or collocated vertiports at hub airports. Such a service would provide the benefits of a convenient vertiport location at one end of a passenger's trip.

Transfer service would enable passengers connecting at hub airports that have collocated vertiports to use CTR for one leg of their trip. Connections could be made to either a feeder airport or to a vertiport in the spoke city.

Two potential CTR missions illustrate where a 40-passenger CTR could fit into the national transportation system:

- *Demand Center to Demand Center Mission*

By operating closer to the true origin and destination of passengers, a CTR can produce savings in access time and cost, allowing an operator to charge a higher line-haul fare. Some passengers are better off or just as well off as they were using alternative transportation means because the CTR has a lower total trip cost for most city pairs, considering fares, access costs, and value of travel time saved.

- *Use of CTRs to Relieve Congestion at Capacity-Constrained Airports*

Large numbers of slots at high density rule (HDR) airports are now allocated to commuter aircraft to allow access to the national passenger transportation system for small communities. If CTR could be used for these missions, this would either reduce delays or allow the addition of larger, more valuable aircraft operations at slot-constrained airports.

There also are other potential CTR missions, including package express and mail, offshore crew change, corporate transport, and medical transport. These other missions have not been investigated in detail for this analysis. Because these other missions imply vehicles of varying sizes, the total market for any one size of vehicle for these missions is likely to be less than the market for the 40-passenger version. In addition, these markets may have less overall public benefit. Therefore, the 40-passenger CTR for commercial service was deemed to be the most appropriate aircraft to examine in the context of national transportation policy.

E2.0 Background: Short-Haul Transportation Market

E2.1 Introduction

This section explores the trends and likely developments through the year 2020 in the supply and demand for air, auto, bus, and rail to serve intercity passenger transportation needs. This discussion describes what opportunities might exist due to changing travel patterns that could enhance the introduction of a new transportation technology such as civil tiltrotor (CTR). Since CTR is most competitive at distances of up to 600 miles, the modal discussions below will focus primarily on short-haul passenger transportation missions.

The short-haul intercity transportation environment is dominated by the private automobile which in 1993 accounted for over 81 percent of total intercity passenger miles. A passenger mile is defined as one passenger carried one mile. Commercial carriers, including air, bus, and rail, account for the remaining share. Among the commercial modes, air dominates with a 91 percent share of intercity passenger miles while bus has 5 percent and rail has 4 percent (reference 2). These market shares reflect national averages and vary considerably in specific markets. Automobile share declines rapidly as trip length increases. Air dominates long-haul markets. In addition, the share of commercial traffic carried by both bus and rail is higher in short-haul markets under 500 miles than it is in more distant markets.

E2.2 Aviation Trends

Air transportation has grown rapidly. Since 1950, U.S. intercity air travel has grown much faster than population and income. Figure E2.2-1 compares the level and growth for domestic enplanements and domestic air revenue passenger miles (RPM) for commercial carriers, U.S. population, per capita RPM, and per capita income from 1950 to 1990.

Years	Enplane-ments	Revenue Pax-Miles	Population	Real Per Capita Income
1950-1960	N/A	14.4%	1.7%	1.9%
1960-1970	N/A	13.0%	1.3%	3.3%
1970-1980	5.9%	7.0%	1.1%	2.1%
1980-1990	4.3%	5.2%	0.9%	1.6%
1990-1993	0.4%	0.7%	1.1%	0.1%

Source: FAA Aviation Forecasts, Fiscal Years 1995-2006

Figure E2.2-1 Average Annual Growth Rates in Domestic Air Travel, Personal Income, and U.S. Population 1950 to 1993

The rapid growth in air travel can be attributed to a variety of factors. From 1950 to 1970, air travel replaced rail travel as the preferred common carrier mode of long-distance intercity travel. During this period, air travel became accepted by the general public as a fast and safe mode of transportation. Between 1970 and 1990, air travel continued to grow at a relatively high rate. This later growth was fueled by a real decline in the price of air travel adjusted for inflation. Average fares per passenger trip have declined from $149 in 1977 to $113 in 1993. Airline yields, defined as revenue per passenger mile, declined from over 20 cents in 1977 to approximately 14 cents in 1993. Much of the price reductions result from changes in Federal policy, such as the passage of the Airline Deregulation Act of 1978 which led to increased airline competition. This increased competition further fueled improvements in operating efficiency that result from the maturation of the airline industry. Figure E2.2-2 shows the decline in the real price adjusted for inflation of air travel in terms of average fare and yield over time. However, some of the declines in real yields are due to increases in passenger trip length, which has grown from an average of 706 miles in 1977 to 800 miles in 1993.

Year	Passenger Revenue (billions of dollars)	Revenue Passengers (millions)	Average Real Fare Per Passenger (1994 dollars)	Revenue Pax-Miles (billions)	Average Yield (1994 dollars)
1977	33.1	221.7	149	156.5	0.211
1978	35.3	253.3	139	182.6	0.193
1979	38.2	287.3	133	205.1	0.186
1980	41.8	270.6	154	198.3	0.211
1981	42.1	258.8	163	193.9	0.217
1982	39.5	270.8	146	205.6	0.192
1983	40.8	294.9	138	225.1	0.181
1984	44.6	318.4	140	242.2	0.184
1985	45.7	354.7	129	270.1	0.169
1986	45.0	388.8	116	301.4	0.149
1987	48.5	416.8	116	324.4	0.149
1988	50.8	419.2	121	329.2	0.154
1989	51.7	415.6	124	330.5	0.156
1990	51.9	423.5	123	340.2	0.153
1991	48.2	410.5	117	331.0	0.145
1992	47.3	429.3	110	347.1	0.136
1993	49.8	441.1	113	353.1	0.141

Figure E2.2-2 U.S. Airline Revenues and Fares - Domestic Adjusted For Inflation (1994 Dollars)

Although the domestic market for air travel has been maturing, significant long-term growth in air travel is still expected. The Federal Aviation Administration (FAA) projects an increase in air travel at a rate faster than the general economy. The latest FAA Long-Term Aviation Forecast (July, 1994) projects air carrier enplanements, excluding regional/commuter airlines, will increase by 3.5 percent annually between 1993 and 2005, compared to a 2.6 percent annual growth rate in real gross domestic product (GDP). Over the extended forecast period of 2005 to 2020, domestic passenger enplanements are projected to increase at an average annual rate of 2.3 percent compared to real GDP growth of 1.8 percent annually.

The regional/commuter airline industry is projected to grow at a much faster pace during both the near-term and extended forecast periods. The FAA attributes much of this growth to the shift of low-density, short-haul markets from larger air carriers to their commuter affiliates. From 1993 to 2005, regional/commuter enplanements are forecasted to increase at an annual rate of 6.9 percent. The rate of growth is expected to slow to 3.2 percent annually from 2005 to 2020. Figure E2.2-3 shows actual and forecast average annual growth rates for domestic enplanements for both air carriers and regional commuter carriers by year from 1990 to 2006 (reference 3).

E2.2.1 Aviation Competition

Until recently, the short-haul air transportation market was characterized by a considerably higher fare structure than long-haul air service. Many of the major carriers developed a hub-and-spoke strategy. The high level of competition kept fares on longer trips competitive. However, this strategy left short-haul flights comparatively expensive on

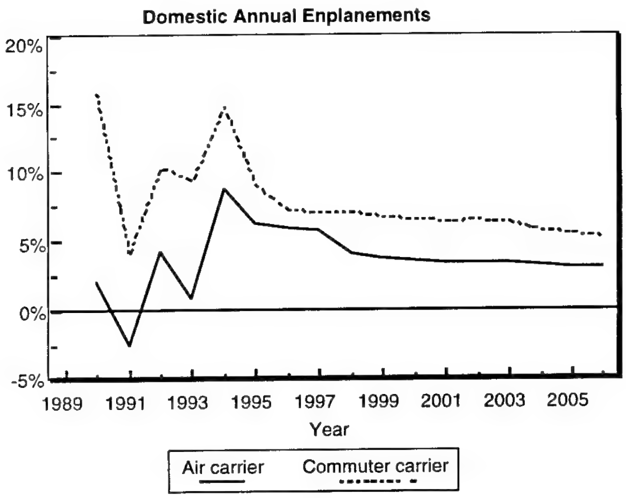


Figure E2.2-3 Domestic Annual Enplanements

a per mile traveled basis, especially in the Northeast. The short-haul market fare structure began to change dramatically in some markets with the emergence of low-cost carriers.

Southwest Airlines began to serve short-haul air passengers profitably with low-cost fares more than a decade ago. After successfully introducing service in the dense travel market between Dallas and Houston, Southwest has penetrated key markets in the Midwest and California, and more recently in some East Coast markets. In California, for example, Southwest has boosted its market share from 2 percent in 1988 to 47 percent in 1993.

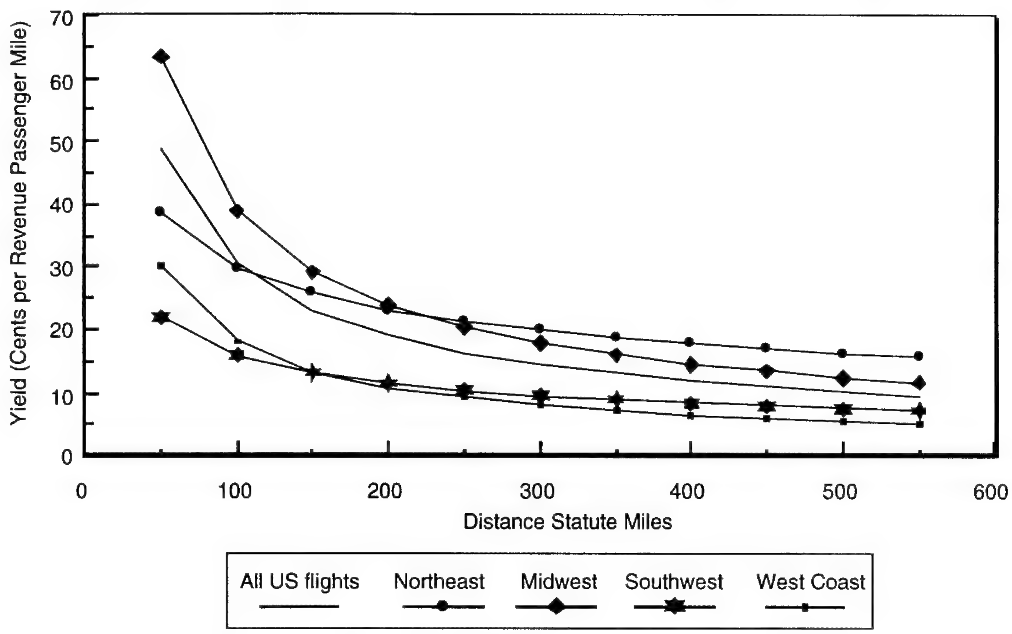
Within the last year, both Continental Airlines and United Airlines have responded to the successful Southwest strategy by launching rival, low-fare services. In October 1994, United launched its "Shuttle By United" in ten markets, the majority in California. United intends to expand the service throughout the West with the expectation that it will eventually account for 20 percent of its domestic operations. To date, the service is performing according to United expectations. Continental Airlines Cal-Light low-cost service, which predates the United service and was spread over a much larger area in the eastern one-third of the country, has proven less successful over a longer term. Cal-Light has been scaled back significantly and is now expected to disappear as a separate product line.

The short-haul, high-frequency, direct-flight market segment in which Southwest Airlines operates makes up only approximately 25 percent of airline industry revenues. This means that there is only so much short-haul service for which the airline industry can compete. Currently, expanding short-haul service has prompted fare wars on both coasts with Southwest and United competing in California, and USAir, Continental, Delta, Kiwi, and very recently Nations Air, contesting the East Coast. Elsewhere in the U.S., start-up or low-cost carriers are chipping away at the dominance of larger airlines at major hubs. The best example of this trend is the success of ValuJet Airlines in Atlanta competing against Delta.

Fares in short-haul markets tend to be higher on a per-mile basis than in long-haul markets. In addition, there may be large fare variations between markets of the same trip distance. Several factors contribute to this variability:

- Airplane operating costs are characterized by fixed (per cycle) and variable (per hour) elements. This produces a very steep cost versus distance relationship.
- Unique geographical features can disproportionately affect journey time (e.g., circuity of airway routing, airport/airway congestion, seasonal adverse weather).
- The operating cost structure of the individual airlines in each market tends to drive the minimum fare structure of that market (e.g., Southwest Airlines between Dallas and Houston).

The net effect of these factors on yield per passenger mile is shown in figure E2.2.1-1. The graph shows typical yields per passenger mile for short-haul air transportation markets in the U.S. These range from approximately 15 to 30 cents per passenger mile for flights of from 200 to 300 miles. Yields vary considerably by market and carrier. For example, the USAir Shuttle yield in 1994 was 59 cents per passenger mile. Horizon had a yield of 34 cents, and Simmons had a yield of 32 cents in 1994 (reference 4).



Source: DOT 10% Ticket Sample 2Q 1994

Figure E2.2.1-1 Short-Haul Airline Yields

The model for successful short-haul airline operations is undoubtedly Southwest Airlines. Southwest Airlines in Texas and Pacific Southwest Airlines (PSA) in California served short-haul markets profitably with low-cost, low-fare service for years prior to airline deregulation. Southwest and PSA dominated their limited intrastate markets. Southwest prospered under deregulation.[1]

The future direction of competition in short-haul airline markets is not clear. The "Southwest phenomenon" has proven that demand exists for a low-fare, point-to-point air product, including new, induced travel. A key uncertainty is whether all air markets are candidates for low-cost service, or whether some markets are unlikely to ever support low-cost carriers due to unique circumstances.

E2.2.2 Aviation Congestion

Although the future competitive market for short-haul aviation is uncertain, it is clear that aviation system capacity is not keeping pace with the growth in total demand. This lack of adequate capacity is reflected by increased flight delays. As the demand for air travel increases, the difficulty in expanding existing airports will lead to greater delays in the future. The metric of 20,000 hours of airline flight delays is often used to define "delay-problem" airports. According to the FAA 1994 Aviation Capacity Enhancement Plan, 23 airports in 1993 each exceeded 20,000 hours of annual aircraft flight delays (reference 5). Assuming no improvements in airport capacity are made, a net of nine additional airports are forecast to each exceed 20,000 hours of aircraft flight delays by the year 2003 (figure E2.2.2-1).

A more meaningful measure of the extent of the flight delay problem is average delay per operation. Unfortunately, the detailed data needed to generate these statistics were not available until recently. Figure E2.2.2-2 lists the seven airports which currently average more than 9 minutes of delay per air operation. By 2005, the number of high delay airports is projected to increase to 18 if no airport capacity improvements are made. Even if all planned improvements are made, the number of delay prone airports will grow to 11 by 2005.

[1] PSA was absorbed by USAir which eventually abandoned the former PSA system when USAir cost structure proved uncompetitive.

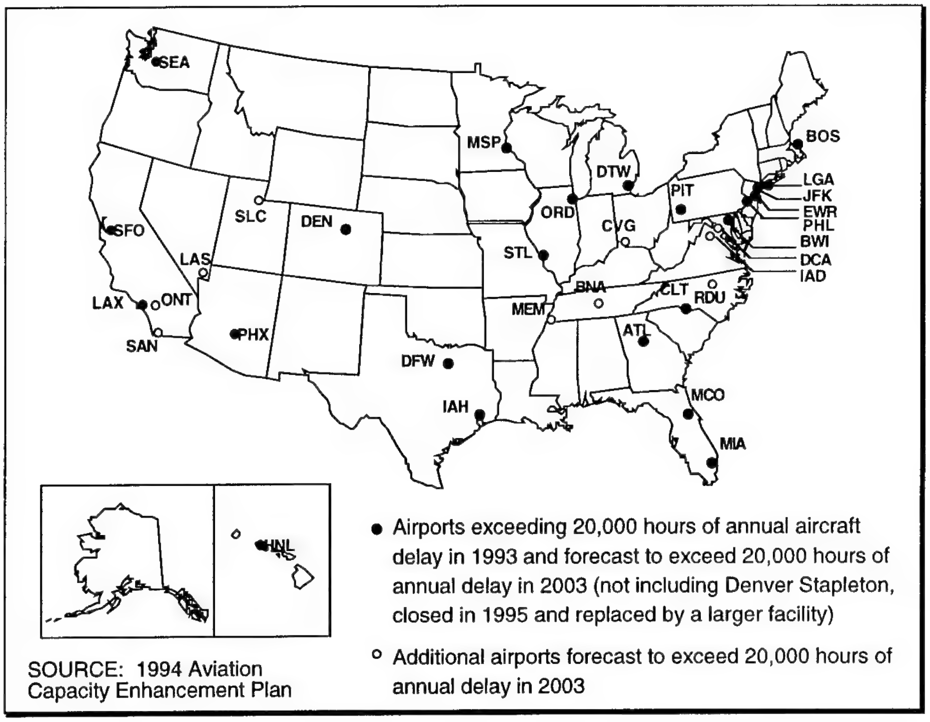


Figure E2.2.2-1 Airports Exceeding 20,000 Hours of Annual Delay in 1993 and 2003, Assuming No Capacity Improvements

A number of factors might mitigate expected increases in aviation delays. First, since more than half of all delays are attributed to adverse weather conditions, proposed electronic guidance and control equipment improvements might allow for extra or more compact flight arrival streams during periods of poor visibility. Second, 62 of the 100 major U.S. airports have proposed new or extended runways, and 17 of the 23 delay-prone airports are planning to construct or extend runways during the next decade. Third, the FAA projects significant increases in the seating capacity of both commuter and air carrier aircraft in future years. This averages more than one seat per year increase. Fourth, Federal noise regulations, which require replacement or hushkitting of Stage 2 aircraft by the turn of the century, may force the retirement of some aircraft, primarily small jets. Finally, forecast increases in average commuter load factors should have a positive, but much more modest, impact on airport congestion. Figure E2.2.2-3 shows FAA projections for aircraft size and load factors from 1993 to the year 2020. Even with all these improvements, delays are projected to increase in the future. Clearly, technology and service innovations which reduce delays can provide large benefits to the national air transportation system.

One approach for reducing aviation delays caused by capacity constraints is to divert short-haul flights from airports. A second approach would be to use aircraft that operate independently of conventional aircraft at airports. Aircraft that serve the short-haul markets (i.e. turboprops and small jets with 50 seats or less) represent one-quarter to one-half of the total operations of many of the busiest airports in the country. The high congestion levels at many of these airports can be attributed, in part, to the demand for short-haul service. In Boston, for example, 44 percent of the departures and arrivals in April 1995 involved aircraft with 50 or fewer seats flying 500 or fewer miles. Figure E2.2.2-4 shows the level of operations that involve aircraft with 50 or fewer seats traveling 500 or fewer miles for ten major airports.

Airport	Identifier	1992 A	2002 B (note 1)	2002 C (note 2)
Boston	BOS	X	X	X
Hartford	BDL		X	X
New York	LGA	X	X	X
New York	JFK	X	X	X
Newark	EWR	X	X	X
Philadelphia	PHL		X	
Washington	DCA*			
Atlanta	ATL		X	
Orlando	MCO		X	
Miami	MIA		X	
Detroit	DTW		X	
Chicago	ORD	X	X	X
St. Louis	STL		X	
Minneapolis	MSP		X	
Dallas	DFW	X	X	X
Denver	DEN	X		
Los Angeles	LAX		X	X
San Francisco	SFO		X	X
Honolulu	HNL		X	X

Note 1: no improvements
Note 2: scheduled improvements
Source: Aviation Capacity Enhancement Plan, 1994
* Assumes no change in number of slots at DCA

Figure E2.2.2-2 Congested Airports (Greater Than 9-Minute Average Delay)

Year	Load Factor		Aircraft Size	
	Air Carrier	Commuter	Air Carrier	Commuter
1993	63.0%	48.7%	151	23
2020	63.0%	52.0%	190	52

Source: FAA Long-Term Aviation Forecast (July 1994)

Figure E2.2.2-3 Projected Increases in Average Aircraft Load Factor and Aircraft Size

Diverting these short-haul flights could provide benefits in two fundamental ways. First, it could slow the expansion of congestion on the roads and airways surrounding airports, both of which constitute a scarce and expensive resource. This reduction in congestion benefits both consumers of air travel as well as others who must

Airport	Total Operations	Percent of Total Operations ≤ 500 Miles and Operated With Aircraft of ≤ 50 Seats
Newark	30,156	28
LaGuardia	26,896	23
JFK	23,775	34
Boston	32,856	44
Washington National	20,892	25
Philadelphia	26,867	35
Atlanta	56,029	17
Los Angeles	60,120	36
Dallas-Ft. Worth	67,525	23
Chicago O'Hare	67,615	17

Source: April 1995 Official Airline Guide

Figure E2.2.2-4 Percent of Short-Haul Aircraft Operations at Major Hub Airports - 1995

share access roads. Second, to the extent the substitution for short-haul air service allows for more long-haul air service, consumers of long-haul air service may benefit from increased supply of air service, expanded destination opportunities, and possibly lower fares as a result of the greater supply.

Taking people out of airports reduces the immediate need to add airport capacity in the form of new runways, terminals, or entire new airports. New runways can cost upwards of $200 million; the new Denver airport cost a total of $4 billion. Taking people out of airports also lessens the need to add other infrastructure such as highways and transit links to carry air travelers between the airport and their true demand center. Most metropolitan areas today lack acceptable options for expanding their existing airports and related infrastructure. Political opposition to expansion is often fierce. Entirely new facilities either encounter similar opposition or must be located so far from demand centers that air travel ceases to be an attractive option for all but the longest trips. New airports are typically located far from demand centers. This increases the time and cost of access and can result in people choosing not to fly for short trips.

E2.3 Trends In Intercity Travel on Highways

E2.3.1 Automobile Trends

Estimates indicate intercity auto travel accounts for approximately 80 percent of total intercity passenger miles. This is only an estimate as there are no ongoing measurements of intercity automobile travel. Unlike commercial air, bus, and rail passenger mile data derived from ticket samples, no such equivalent data collection opportunity exists for auto travel beyond periodic surveys. The latest National Personal Transportation Survey (NPTS) indicates that, on average, U.S. citizens take approximately 11 auto trips of more than 75 miles each year. This accounts for less than 18 percent of total automobile miles traveled per year in the U.S.; the rest is travel for local trips. Statistics for rural vehicle miles traveled (VMT), which account for approximately 40 percent of total automobile travel, are sometimes used as an imperfect substitute for intercity highway travel. This is important because a significant percentage of intercity highway trips are thought to be taken on rural roads.

Between 1950 and 1990, rural VMT grew at a compound annual growth rate of 2.9 percent. With population growing at a 1.2 percent annual growth rate over this same period, per capita rural VMT, and by implication intercity VMT, might have increased by approximately 1.6 percent per year. The growth in per capita VMT, like that of RPMs for the airlines, grew substantially during the 1950s and 1960s. It was a period of time with marked increases in automobile ownership and per capita personal income.

As with aviation capacity constraints, demand for highway use is exceeding design capacity, resulting in delays. The Federal Highway Administration (FHWA) produces an approximate measure of highway congestion through its Highway Performance Monitoring System. Traffic congestion affects highways in metropolitan areas much more than in rural regions. A typical lane of urban interstate highway carries three times the traffic volume of its rural equivalent. As a result, FHWA measurements show only 9.3 percent of rural interstate route-mileage to be congested, while 46 percent of the urban route-mileage is considered congested. The percentage of urban interstate mileage that is considered congested has doubled from 1975 to 1992. Even on rural interstate highways, which are comparatively less prone to deteriorating levels of service, peak hour congestion has more than doubled between 1983 and 1991.

Another way to measure highway congestion is by measuring increases in travel per lane-mile. For the 8-year period from 1983 to 1991, total highway travel increased at an annual rate of 3.5 percent, including 2.9 percent rural and 3.9 percent urban. During this period, VMT per lane-mile grew at an average rate of 2.6 percent per year. Because lane-miles of highway expanded much more rapidly in urban areas, estimated daily travel per lane mile in rural roads grew at a faster rate (3.2 percent per year) than urban highway travel per lane-mile (2.2 percent per year).

Paradoxically, measureu average highway speeds have been increasing within the last two decades, particularly on rural highways. Some of this effect could be attributed to changes in rural interstate speed limits. However, since increased highway congestion does not seem to have led to lower highway speeds at least on measured segments, it has probably not impacted average intercity travel times significantly (reference 6).

E2.3.2 Trends in Intercity Bus Travel

Intercity bus ridership accounts for only a small portion of total national intercity commercial passenger miles. National ridership numbers leveled off in the 1980s after sharp declines since the interstate highway system made personal auto travel more attractive for short trips and airlines took over long-haul traffic during the 1960s and 1970s. Bus data failed to show any significant increase in 1971 when the establishment of Amtrak eliminated two-thirds of national rail passenger service.

Nevertheless, bus travel in short-haul markets has fared better than the national average would

imply. Bus deregulation has allowed many large carriers to rationalize their route structure and drop unprofitable long-haul routes. Many new smaller carriers also appeared during the 1980s specializing in short-haul service, some of it in conjunction with Amtrak in arrangements similar to airline code sharing.

E2.4 Trends In Intercity Rail Travel

E2.4.1 Historical Perspective

For the first half of the twentieth century, the railroads were the primary providers of intercity transportation in the U.S. The demand for intercity rail service in the U.S. dropped dramatically in the 1950s and 1960s as development of the Interstate Highway System siphoned off short-haul travel and the public began accepting air travel as a preferred mode of long-distance travel. The decline was further hastened by regulatory policies which hindered attempts by the railroads to initiate price and service changes in response to changing market conditions. Routes, fares, frequencies, and on-board service levels were all subject to regulation. Proposed changes in fares or service typically required 3 to 6 months for approval, if given at all. Any notion of modern market-based pricing such as seasonal sales or competitive pricing taken for granted in today's deregulated market was impossible. For this reason, an industry which formerly had a monopoly on commercial travel was losing it and had no marketing recourse. While many fast intercity routes offering premium service remained profitable, passenger service, as a whole, had become unprofitable. Regulations mandated the continued operation of services that had become unprofitable shortly after the invention of the automobile. These included slow local intercity service with stops at every small town and extensive urban/suburban commuter services.

During the same period, other national regulations mandated that maximum train speeds could no longer exceed 79 miles per hour. This substantially impacted both short-haul and long-haul limited-stop, premium express services which regularly operated at speeds of 90 to 110 miles per hour over portions of nearly all major U.S. intercity routes. Only after installing a special new and expensive signal system would trains be permitted to operate at their former speeds. With overall passenger service losing money and no regulatory freedom to respond to changing market conditions, few railroads were willing to make the necessary investments. In addition, national regulatory bodies refused to intervene in the growing number of states and municipalities that began to regulate interstate commerce by placing local speed limits on railroads. Extreme examples saw speeds drop to under 5 miles per hour. Even speeds on fully grade separated rights-of-way were reduced to 20 to 30 miles per hour by some communities. The only recourse of the rail industry was a slow and expensive legal challenge to each individual restriction. Nearly all these restrictions remain in effect in modified form today, although some states have codified the restrictions at the state level, reducing the appeal process.

In 1962, changing national policies unofficially closed the door on any future for private sector rail passenger service when the Railway Trust Fund was terminated. The rail ticket tax monies were rolled into the U.S. General Fund.

E2.4.2 Amtrak Arrives

By the late 1960s, the private sector railroads had given up hope of maintaining any profitable passenger service and accelerated efforts to discourage use by purposely providing poor service in the hope of being permitted to abandon all passenger service. In 1971, the railroads got their wish with the creation of Amtrak which took over approximately one-third of the remaining intercity rail passenger services. The other two-thirds were discontinued, except for urban/suburban commuter services which over time were transferred to local urban transit authorities.

Amtrak currently operates a combination of medium- to high-frequency services in short-haul, high-density markets and almost daily service on long-distance, low-density routes. Amtrak frequencies in major short-haul corridors are shown in figure E2.4.2-1.

Corridor	Round Trips Per Day
New York - Washington	37
New York - Boston	12
New York - Albany	11
Springfield - New Haven	9
San Diego - Los Angeles	9
Chicago - Milwaukee	7
Oakland - Sacramento	5
Washington - Richmond	7
Chicago - St. Louis	4
Oakland - Bakersfield	4
Albany - Buffalo	4
Chicago - Detroit	3
Seattle - Portland	3

Note: Some listed service scheduled for reduction in April 1995

Figure E2.4.2-1 Amtrak Frequencies in Major Short-Haul Rail Corridors - 1994

The success of Amtrak at restoring rail passenger service as a viable means of intercity travel has been mixed. On routes where new equipment operates, the service has been well received in both short- and long-haul markets. On routes where only refurbished equipment operates, service acceptance has varied, often in a direct relationship to how recently refurbishment took place. Amtrak, however, fell well short of its original financial goal of becoming self sufficient by 1975. System-wide operating cost recovery has improved from less than 30 percent in 1971 to between 65 and 82 percent today, depending on the accounting method used. Regardless of accounting method, Amtrak today financially outperforms all other national rail passenger systems in the world. Amtrak began a restructuring in the fall of 1994 to concentrate its limited resources on those routes with the best prospect of financial self-sufficiency and retired nearly all of its oldest equipment, some of which exceeded 45 years of age. Amtrak now expects to achieve operating cost self-sufficiency by 2002. Capital expenses for infrastructure-related items such as track, traffic control systems, and stations would continue to require state or Federal Government investment.

E2.4.3 Rail Market Share

As previously noted, the share of the commercial intercity passenger market held by rail is low when viewed on a national level. It is, however, much higher in some short-haul, high-density markets, especially where federally mandated signal systems permit operations at speeds faster than 79 miles per hour.

Rail has enjoyed its greatest success in the Northeast Corridor. Rail dominates the common carrier market with approximately 70 percent of the total commercial market when all intermediate cities are included, although air dominates the more distant city pairs. Rail and air currently split the New York/Washington intermediate distance endpoint markets with 45 percent and 55 percent shares, respectively. Air, however, dominates the New York/Boston market despite its similar intermediate distance with an 80 percent share versus a 20 percent share for rail.

The success of rail in competing with air in the Northeast Corridor is a function of competitive total travel times which result from fast line-haul speeds up to 125 miles per hour and stations located in the heart of the central business district demand centers as well as some key suburban locations. Rail fares for the fastest service are comparable to airfares. The Boston - New York section of the route is currently being upgraded to permit maximum speeds to rise from the current 100 miles per hour to 150 miles per hour. Most of the track upgrading is complete. The remaining work involves extending electrification of the track from New Haven to Boston and purchasing new high-speed electric train sets.[2] Both items are funded by the Federal Railroad Administration (FRA). The

[2] Electric trains generally can accelerate significantly faster than conventional diesel trains, a key ingredient on the New Haven - Boston route with its many curves which necessitate speed restrictions. In March 1995, however, an existing 110 mile per hour jet fueled, turbine powered train, as currently used between New York and Albany, was tested in the Northeast Corridor with a more powerful engine. The train achieved 125 miles per hour with

start of electrification construction and awarding of the contract for trains is scheduled for November 1995. Faster service is scheduled to commence on the Boston - New York portion in 1998. Express train line-haul time is expected to drop from 4.5 hours to just under 3 hours, comparable to the current New York/Washington line-haul time. The FRA forecasts that rail ridership between Boston and New York will increase from approximately 2 million passengers in 1993 to 5 million passengers upon completion of the electrification project. The FRA Final Environmental Impact Statement on the project forecast that the improvements will reduce the number of air passengers traveling between New York, Providence, and Boston. This will free up scarce aviation capacity for delay reduction or new services (reference 7). The new trains will also permit 150 mile per hour operation on those portions of the New York - Washington route that currently permit 125 mile per hour operations. This will be possible without upgrading additional infrastructure due to the faster acceleration and braking capability of the new trains. This will permit a reduction in endpoint trip times on the fastest schedules from 3 hours to 2.5 hours.

Outside of the Northeast Corridor, the commercial market share for rail is higher than the national average in short-haul markets that have frequent rail services. These include routes in the Midwest radiating from Chicago and on the West Coast in southern California, the San Francisco Bay area, and in the Pacific Northwest between Portland, Seattle, and Vancouver, B.C.

E2.4.4 Long Term Prospects for Rail

The future of intercity rail passenger service provided by Amtrak has always been uncertain and difficult to predict. Since the beginning of Amtrak in 1971, financial investment has consistently fallen short of the amount required to repair the deteriorated rail passenger service infrastructure to a level consistent with the quality and scope of service Amtrak was commissioned to provide. Under the current budget circumstances, it is possible that Amtrak could cease to exist. It is unlikely, however, that intercity rail passenger service will simply go away, especially in high-density markets. Congestion mitigation needs prohibit such an alternative. In the case of the Northeast Corridor, Amtrak carries over 10 million intercity passengers annually. This number excludes the many intercity passengers who opt to use slower, low-cost local commuter services for intercity travel. This is possibly due to the proximity of cities along the Northeast Corridor and their overlapping urban/suburban transit systems that also operate over the same route used by Amtrak high-speed trains.

While the prospects for new very high-speed (above 150 miles per hour) rail service on new dedicated rights-of-way in the U.S. appears uncertain in the near future due to high cost, incremental upgrading of existing routes has been progressing since the late 1970s. State-funded initiatives to restore fast rail service where it once existed by funding signal system and grade crossing improvements have been completed or are underway in California, Florida, Illinois, Maine, Maryland, Massachusetts, Michigan, New Jersey, New York, North Carolina, Ohio, Virginia, Washington, and Wisconsin, among others. Speeds where improvements have been completed generally range from 90 to 110 miles per hour. Even faster speeds are possible on many routes that do not require realigning rights-of-way. Historically, U.S. railroad rights-of-way were laid down significantly straighter than those in Europe. This is due to the fact that Europe was much more densely populated than the U.S. during the railroad building era of the nineteenth century. In the U.S., towns developed along railroad rights-of-way, most of which were built on unoccupied territory. In Europe, railroads had to take twisting paths through already populated areas.

an acceleration rate comparable to the existing 125 mile per hour electric trains used on the Northeast Corridor and with 30 percent less fuel consumption than an unmodified turbine train at 110 miles per hour. The success of this test demonstrates that faster rail service does not necessarily require expensive electrification. Expensive new straight rights-of-way are also not essential for faster rail service. New technology tilting trains permit up to 40 percent faster speeds on curves than traditional trains. This technology is under consideration for the New Haven - Boston route as well as other routes around the country. The State of Washington is currently testing a tilting train in revenue service between Seattle and Vancouver, British Columbia.

Congress has commissioned a study on the potential for development of high-speed ground transportation (HSGT) similar to this study of CTR. As required by the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), a Commercial Feasibility Study is being conducted of the potential market for HSGT services in the continental U.S. This evaluation will consider both fossil fuel powered and electric steel-wheel on steel-rail trains with speeds ranging up to 200 miles per hour. Three hundred mile per hour magnetic levitation (MAGLEV) trains are also included. The economic assumptions and demand analysis methods used in the HSGT analysis, while not identical, are largely consistent with the assumptions and methods used in the CTR viability study.

While final results of the HSGT study will not be available until early 1996, some initial trends can be identified:

- HSGT and CTR share many of the same potential markets, i.e., city pairs less than 500 miles apart.

- Estimated MAGLEV travel times are often comparable to times for CTR services, while other HSGT technologies have considerably longer line-haul travel times. Access/egress and terminal travel times are expected to be similar for both modes.

- Rail services would probably be priced below the level of existing air service, and consequently would attract a greater percentage of existing auto and rail passengers than CTR, as well as a larger share of non-business air passengers.

- In markets that they may both serve, HSGT is generally expected to attract as many or more passengers than CTR service. The extra high-speed rail (HSR) passengers would likely be derived primarily from existing auto and rail passengers. Lower speed HSGT options would probably attract fewer riders than new electric rail and MAGLEV.

- The total cost of new electric rail and maglev vehicles and infrastructure (mainly guideway) are estimated to be many times larger than required for CTR aircraft and a network of vertiports. Lower speed rail capital costs are estimated to be closer to CTR financial requirements.

- Projected revenues from improved HSGT services can be expected to cover operating costs in many potential applications. However, government investment will be required to finance initial infrastructure requirements, especially for new electric rail and maglev options.

E2.4.5 CTR/Rail Synergies

For years transportation planners have envisioned intermodalism as a key component for reducing congestion. Historically, however, national transportation policies encouraged all modes of transportation to pursue all ranges of short-, medium-, and long-haul needs. Today, new Federal policies are emerging to encourage maximizing the nation's limited transportation capacity by encouraging participation of all modes linked efficiently in an intermodal network. Intermodalism encourages each mode to maximize its inherent advantages and allows the passenger or shipper to choose the mix of modes that provides the most economically efficient transportation given the passenger's (or shipper's) value of time.

Locating CTR vertiports near or at major Northeast Corridor rail stations could maximize intermodal opportunities. Most U.S. airports, with the notable exception of BWI, are not directly served by high-speed rail. CTR can link airports with high-speed rail stations and with other demand centers where neither rail nor fixed-wing aircraft can operate today or possibly in the future. In addition, many urban rail stations possess air rights development opportunities over adjacent rail yards which could provide excellent locations for urban vertiports. Although CTR and high-speed rail will compete on some routes, they will compliment each other on other routes. Capitalizing on such intermodal opportunities could have substantial congestion relief benefits for both airports and highways.

E2.5 CTR Potential To Meet Demand

CTRs offer the potential to develop new types of intercity passenger transportation markets. Because of the development of the V-22, the U.S is at the forefront of this technology, with a substantial lead-time advantage over foreign countries in the ability to apply this technology to civil aircraft. As a result, there are potentially large benefits to the U.S. economy if the market for CTR vehicles can be developed in a timely manner.

A major irony of modern jetliner transportation is that much of the total travel time is spent on the ground. For journeys under 700 miles, passengers typically spend over half of their total travel time on roads accessing or egressing an airport, at the airport terminal checking in or passing through security, in the aircraft taxiing around the airport, and/or otherwise waiting in a queue for any of the above.

Since the invention of the helicopter, transportation visionaries have thought that one day vertical flight would provide the next step in the evolution of transportation, near doorstep-to-doorstep carriage. Unfortunately, helicopters have not evolved radically from the time of their invention to modern times, unlike a Boeing 747 of today which bears only a small resemblance in form, function, and comfort to the first airplane of the Wright brothers. In general terms, helicopters remain small compared to a modern jet aircraft, and are perceived by much of the traveling public to be uncomfortable compared to a modern turboprop. In absolute terms, existing helicopters are limited to forward speeds of less than 200 miles per hour which is considerably less than the speed projected for CTRs.

Developing a totally new short-haul transportation system will require a cooperative effort of aircraft manufacturers, airlines and government. The remainder of this report discusses the commercial, economic, and social viability of CTR. Potential markets are identified. Direct and indirect benefits are analyzed. These range from congestion relief and delay reduction potential, especially at High Density Rule (HDR) airports, to the export trade potential of CTRs. Economic barriers to private sector investment in CTR are discussed as they relate to vehicle manufacturing economics and the concurrent need for vertiport infrastructure to attract investment from both manufacturers as well as airlines. Finally, further research and development requirements are identified and discussed relative to the traditional Government role in U.S. civil aeronautics.

E3.0 Methodology

E3.1 Introduction

This chapter introduces the methodology, assumptions, and models used by the Economics Subcommittee to assess the viability prospects of civil tiltrotor (CTR). Although this chapter provides a comprehensive overview of these topics, subsequent chapters reveal additional detail. In-depth discussion of results, assumptions, uncertainties, sensitivities, and model nuances appear in complete form as individual topics later in the report. However, prior to any further discussion of the methodology used to assess CTR viability, the term "viability" must be defined.

E3.2 Alternate Measures of Viability

A key question facing the Civil Tiltrotor Development Advisory Committee (CTRDAC) was CTR viability. This analysis required looking at the commercial, economic, and social viability aspects of CTR technology investments. This assessment took into account all of the potential benefits and costs that could arise from the development of CTR. However, the underlying question that always needs to be discussed when looking at viability is "viability to whom?". Through this method it will be possible to estimate the benefits of developing CTR as a new aeronautics technology.

The commercial viability of CTR depends largely on the general acceptance of the vehicle by both the airline industry and the traveling public. A private company would only undertake development and production of CTR if a profitable commercial market exists for the aircraft. CTR will be a commercially viable product if the innovating firm can earn a return on its investment that is large enough to allow it to recover its development costs. Commercial viability can be analyzed by looking at the discounted cash flows for CTR manufacturers and operators based on appropriate private discount rates. A private sector firm will invest when the expected cash flows are positive after being discounted at the firm's opportunity cost of funds.

The concept of economic viability for CTR is based on the potential for economic benefits to be "transferred" between various groups involved. CTR could help entities other than the operator to reap economic benefits through its unique operating characteristics. For example, if CTR is introduced at an existing airport, the possibility for additional capacity exists without increasing the number of slots. This is possible because CTR does not require runways to conduct operations. Therefore, overall capacity can be increased which, in turn, could mean increased revenues from airport concessions and aircraft operations. The airport would be able to compensate the CTR operator. At a congested airport, this would be most likely when the CTR was used to replace operations by small aircraft, allowing additional operations by large aircraft.

The social viability of any new aviation project is measured by its potential effect on social benefits and costs, e.g., airport congestion and air quality. CTR will be socially viable if the net present value (NPV) of the social benefits exceed the social costs when discounted at an appropriate social discount rate. This rate is generally lower than the private discount rate because the Government has a more diverse portfolio of investment opportunities. The question of social viability should be answered even if the necessary transfers of benefits among parties cannot take place. Analyzing these questions and finding appropriate answers may help justify funding for a new vehicle on the basis of its social benefits. An example is the possibility that CTR introduction could allow for some reduction

in runway operations at airports. This reduction in operations could reduce the amount of time the remaining aircraft are delayed waiting to take off or land. This reduced delay could then result in either shorter flight times, a benefit to airlines and air travelers, or the opportunity to schedule additional flights.

This chapter discusses the methods used to assess the commercial, economic, and social viability of CTR development, production, and operation in the U.S. These analyses consider a 40-passenger CTR used in scheduled intercity transportation missions in the U.S. Other vehicle sizes and mission types might also be viable, but they are not investigated in detail in this report.

E3.3 Market Analysis Assumptions

Market analyses were conducted for various intercity passenger transportation scenarios, including economic and travel projections as well as CTR and other existing mode fare and performance estimates. The mode choice model used was developed for the Volpe National Transportation Systems Center. Four potential market areas were considered: Northeast, Midwest, West Coast, and Southwest. Analyses were conducted at the city-pair level, with estimates of modal trips, access/egress, and line-haul travel times and costs aggregated to represent metropolitan area averages. In most cases, the city was represented by its Metropolitan Statistical Area (MSA). Calculations were carried out in constant 1994 dollars using the real discount rate of 7 percent recommended by the Office of Management and Budget (OMB). A risk premium is used when evaluating manufacturer and operator returns. In addition to CTR, the model assesses air, auto, and rail modes. Diversion estimates were made from each of the existing modes, and for business and non-business trip purposes. The air mode was separated into jet and turboprop, as well as origin-destination and transfer trip segments.

The analysis was conducted assuming steady-state conditions, i.e., all instabilities in ridership, revenues, and costs attributable to start-up of CTR operations have subsided. The mode choice analysis assumes a mature CTR system after the market introduction phase and covers the period 2010 to 2030. However, the discounted cash flow analysis in Chapter E7 of this technical supplement explicitly considers a start-up phase of operations.

The analysis assumes the CTR2000 concept design, with seats for 40 passengers and a normal cruise speed of 360 miles per hour A slightly slower, 19-passenger variant of the CTR2000 was examined in a sensitivity analysis. Three types of CTR service were examined: (1) urban area vertiport to urban area vertiport, (2) regional airports within 500 nautical miles of urban area vertiports (feeder service), and (3) CTR service to air transfer passengers through a collocated vertiport at congested hub airports.

Vertiports were assumed to exist in major city centers, surrounding suburban locations, and congested hub airports in major cities with one or more other vertiports. CTR service to regional airports was assumed to use conventional airport facilities. The number of vertiports in a major city was set to be sufficient to meet the projected travel demand. The first vertiport was assumed to be located in or near the city center. This siting produces the largest advantages in access/egress travel time and cost for CTR. Access/egress times vary by city size and take into consideration present highway congestion and the number of airports and vertiports.

CTR was assumed to be regarded by travelers as equal to turboprops in amenities, comfort, and safety. This implies that the mode preference for CTR compared to turboprop aircraft is zero. Mode preference is defined as the amount a traveler would prefer one mode over another if their travel time, cost and frequency were equal. Travelers were assumed to have a mode preference for jet travel over both CTR and turboprop. At an average trip length of approximately 200 miles, the mode preference is equivalent to $18.00 for business travelers and $15.00 for non-business travelers. The value of the mode preference constant increases with trip distance, so that the preference is one-third higher at 500 miles than at 200 miles.

Passengers using vertiports, which will be smaller and simpler than major airports, were assumed to have shorter terminal processing times of 5 to 10 minutes less than airports. CTRs were assumed to follow existing turboprop routes between cities, but to fly directly to vertiports without significant delays once in the terminal area. When CTRs operate at feeder airports they were assumed to be subject to the same delays as fixed-wing aircraft.

CTR line-haul travel times were calculated from typical flight profiles adapted from manufacturer design guidelines and assume an average CTR flight circuity[3] of 13 percent and a travel-time increase of 5 percent to account for scheduling inefficiencies and normal facility congestion delays. Due to the considerably smaller expected size of vertiports, CTR taxi-in and taxi-out times were assumed to be shorter than for fixed wing aircraft at major airports, averaging 4 minutes per CTR operation.

Consistent with Federal Aviation Administration (FAA) projections, future potential air traffic in primary markets for CTR passengers of less than 500 miles was assumed to grow until 2030 at a rate only slightly greater than population and income growth in these corridors. At an annual growth rate of just under 2 percent, this implies that air travel in the Northeast corridor would double between 1995 and 2030.

Video conferencing and other communications technologies were assumed not have a major impact on air travel. The share of business air travel was assumed to remain the same as it is today, averaging approximately 48 percent nationally. The share of business air travel was assumed to decline with distance traveled, ranging from 59 percent at less than 200 miles to 34 percent at greater than 500 miles.

Load factors in short-haul conventional air markets of less than 500 miles are typically 10 to 15 percent lower than the national average for total air travel, which was approximately 66 percent for 1995. The study assumed small increases in load factors according to the FAA Long-Term Forecasts of 2 percentage points every 10 years for regional airlines and .75 percentage points for major airlines. A load factor of 60 percent was assumed for CTR.

Conventional airfares were assumed to remain approximately at current levels in real terms in future years. Adjustments to 1992 airfares were made to account for recent fare fluctuations in the Northeast and some Midwest markets. Additional factors that might either reduce future airfares (e.g., the spread of low-cost carriers) or increase fares (e.g., higher aviation fuel, airframe, or airport costs) were examined as part of sensitivity analyses. On average, business airfares are higher than pleasure fares due to more limited use of discount tickets. CTR fares were set at levels sufficient for CTR operators to recover operating costs plus earn a return of 10 percent in each market served. CTR fares were assumed to include the 10 percent ticket tax. It is likely that CTR ticket prices will need to be higher than conventional airfares in most markets because of higher anticipated initial purchase and operation and maintenance (O&M) costs of the CTR. This higher fare is offset by reductions in access time and costs.

Changes in future fixed-wing air delays at congested airports were analyzed in sensitivity analyses. The base case assumes that aviation line-haul travel times remain at current levels. The FAA projects that increases in the number of conventional air operations at many airports will likely lead to higher air system delays in the next decade (reference 8). However, long-term delay forecasting is quite uncertain. Several developments could reduce aviation delays below expectations, including the introduction of new technology (e.g., the use of the Global Positioning System (GPS) for air traffic control), added runway capacity or use of reliever airports, changes in airline hubbing practices, increased aircraft sizes and higher average load factors, and diversions to high-speed rail and CTR.

[3] Flight circuity measures the difference between miles actually flown and great-circle distances.

CTR system operating costs were estimated for the following expense categories:

- Aircraft ownership
- Fuel
- Air crew
- Maintenance
- Landing and ground property and equipment fees
- General, administrative, and other miscellaneous costs

The baseline CTR aircraft purchase price was assumed to be $18.5 million, which is midway between the manufacturer estimates of a $17 to $20 million selling price. A distance-based operating cost function was used to compute CTR costs.

CTR costs assume point-to-point operation with no complex routing among multiple vertiports in a city. Costs assume evenly spaced flight schedules over a 16-hour day. CTRs were assumed to operate an average of six days a week. CTR aircraft requirements were calculated assuming 2,300 average annual flight hour utilization per aircraft.

The vertiport cost model (paragraph E3.4.4) allows for analysis of several vertiport types and locations including: elevated, on-ground, on-piers; downtown, suburban, airport; and new versus adapted existing facility. Elongated, 400-foot touchdown and lift-off (TLOF) surfaces were assumed. Generalized vertiport designs are based on providing an instrument flight rules (IFR) capability, and for a 9-degree precision approach. Although capable helicopters might be able to share use of vertiport facilities, no additional costs or revenues were assumed for helicopter operations.

Vertiport sizes, including number of gates and landing areas, were set to match expected CTR demand. Vertiport land area requirements include buildable space for airside and landside facilities and cleared space for imaginary approach surfaces. Typical downtown or suburban vertiports would occupy 10 to 30 acres. Taking into account noise considerations, approximately 120 acres of area might be impacted at the 65 DNL noise level.

Overall vertiport capacity was calculated assuming TLOFs could handle, on average, 12 takeoffs and 12 landings per hour, and the CTR minimum turn around time would be 20 minutes between arrival and departure of the same vehicle. One spare gate per vertiport was assumed for emergencies.

Vertiport capital costs include airside (i.e., landing areas, taxiways, ramps, gates, lighting), and landside (i.e., terminal and auto parking) requirements costs. Cost for passenger bridges, aircraft rescue and fire fighting equipment, fueling and maintenance facilities costs were also included. Vertiport costs for air traffic control (ATC) (i.e., tower, landing system, and flight services) facilities are included. However, planning, noise abatement, and Environmental Impact Statement costs were not included, although the model does include a 25 percent charge for project management and contingencies.

Vertiport O&M costs were assumed to be similar to those of small airports at $2.10 per passenger. This assumes that there will be offsetting concession revenue from food service, auto parking, and rental cars.

E3.4 Civil Tiltrotor Evaluation Models

A number of demand, cost, and impact evaluation models were developed to assess the market demand and financial feasibility of scheduled passenger service using CTR aircraft. The fundamental economic assumptions and model structures used in the CTR market analyses were consistent with similar methods developed by the Department of Transportation (DOT) for evaluation of high-speed ground transportation systems. The analysis methods allow for estimation of CTR passenger diversion rates, CTR revenues and costs, and requirements for CTR aircraft and facilities. In addition, models of external social impacts, primarily airport congestion and emissions affecting air quality, provide the basis for determining if there is a justification for Government investment in CTR technology.

Market analyses were conducted for various economic and transportation scenarios involving scheduled CTR passenger service in the years 2010 to 2030. Four potential market areas were considered: Northeast, Midwest, West Coast, and Southwest. For each scenario, diversion estimates are made from each of the existing modes (i.e., air, auto, and rail) and for business and non-business trip purposes. The air mode is separated into jet and turboprop, as well as origin-to-destination and transfer market segments.

Market analyses consist of iteratively applying sub-models to develop estimates of:

- Travel in the base year by existing modes.
- Travel projections in future years (2010 to 2030).
- Modal characteristics in future years (i.e., travel time, fares, frequency, etc.).
- Diversions to the proposed CTR service.
- Costs of acquiring CTR aircraft, and vertiports.
- Costs of operating the CTR enterprise.
- Social impacts related to introduction of CTR service (e.g., airport congestion, energy, and emissions).
- Financial summary measurements (e.g., estimates of revenues and costs in future years).

Figure E3.4-1 shows the relationships between the various modeling components.

CTR fares are assumed to be set at levels sufficient for CTR operators to break even in each market served, including an operating profit margin. In addition, the number of vertiports and the frequency of CTR operations are adjusted to be consistent with forecast CTR traffic volumes.

E3.4.1 Market Demand Models

A three-step market demand process was developed based on the concept that the introduction of a new mode such as CTR will result in individuals reconsidering the attributes of each of the modes, and then selecting one which best satisfies their travel requirements. The decision as to which mode to use is driven by how the individual values his/her time, which varies by trip purpose, and the effect of individual preferences for the available modes.

The process begins with the estimation of existing and future year travel by market segment (air, auto and rail) and trip purpose (business and non-business). A set of models are then run to quantify at what rate passengers will be diverted from each of the existing modes to the new mode. The third step is to estimate the amount of travel that is induced once a new high-speed common carrier service is introduced to the marketplace. Induced demand varies based on the diversion rate in each market pair. On average, induced demand is less than 5 percent of diverted passengers.

Base year air carrier travel by city pair was estimated using data from the DOT 10 percent

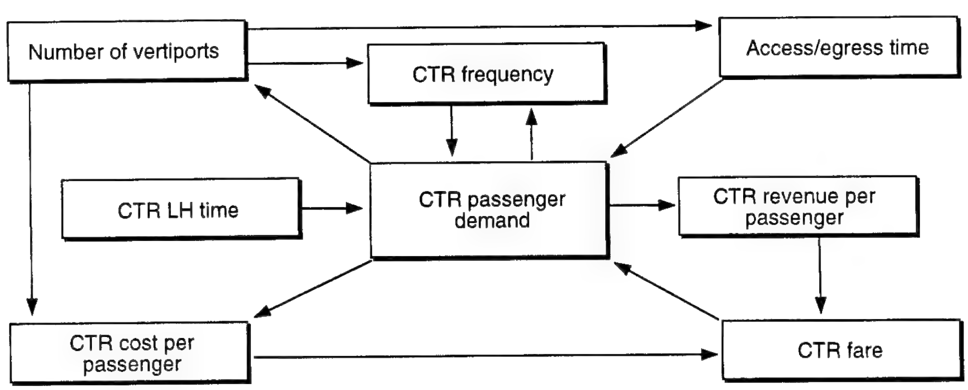


Figure E3.4-1 CTR Model Component Interactions

ticket sample. Base year commuter carrier travel (i.e., small airlines) came from data filed with DOT on Form 298C. To estimate future year air travel, growth factors were applied which were, in general, consistent with the FAA long-range traffic forecasts. Base and future year estimates were segmented to determine the number of: (1) origin-destination and transfer passengers, (2) business and non-business travellers, and (3) jet and turboprop passengers. These data were available from a number of DOT data sources, including 10 percent Ticket Sample, Commuter Airline Traffic Tape, and the T100 Segment Traffic Tape.

Specifically, the T100 Segment Traffic data were used to estimate the split between jet and turboprop aircraft. Figure E3.4.1-1 indicates that lower turboprop use occurs between major cities separated by longer distances.

Market	Percent Jets	Percent Turboprops
Los Angeles - San Francisco	98	2
Boston - Washington, D.C.	98	2
Boston - New York	86	14
New York - Washington, D.C.	83	17
San Diego - Los Angeles	57	43

Figure E3.4.1-1 Percentage of 1992 Passengers Traveling by Jet and Turboprop in Short-Distance Markets

Similarly, assumptions were made using data from three Nationwide Personal Transportation Surveys (NPTS) and one U.S. Travel Data survey to estimate the trip purpose split between business and non-business by distance block. These splits by distance are shown in figure E3.4.1-2.

Base and future year auto travel was estimated by city-pair using a Volpe Center direct demand model. However, considering the low level of rail passengers in the U.S., no mathematical model was developed to estimate rail ridership. Instead, future year ridership numbers were developed by applying growth factors to 1993 Amtrak passenger numbers.

Distance (miles)	Percent Business	Percent Non-Business
< 200	59	41
200 to 299	53	47
300 to 399	51	49
400 to 499	48	52
> 500	34	66

Figure E3.4.1-2 Estimated Air Travel Business and Non-Business Shares by Travel Distance

The set of mode choice or diversion models that were used as part of this effort were based on research conducted on customer preferences in a number of U.S. and Canadian corridors. The models were refined over time as more data were collected from each of the corridor studies. Further refinements to the models were made to assess the market feasibility of maglev and other high-speed ground transportation alternatives. Similarly, for the purpose of this study, revisions were made to the models, particularly to the mode bias coefficient, to account for individual preferences between conventional travel and CTR.

E3.4.2 Market Share (Diversion) Forecasting Models

The market share (diversion) forecasting models consist of ten separate market segment mode choice models. These includes business and non-business models for five market segments: (1) local air, (2) connect air, (3) auto, (4) rail, and (5) bus. Each of the models includes a variety of explanatory variables, including separate line-haul (in-vehicle) time, access and egress time, wait time, and travel cost (or fare) variables. A separate high-speed mode preference constant or mode bias coefficient was also estimated in each model to reflect an expected preference for or against CTR. Figure E3.4.2-1 shows a simplified version of the models.

Implicit in each of the models is how the travelers of the different market segments value time, which is itself a reflection in the variation of average incomes. On a comparative basis, these

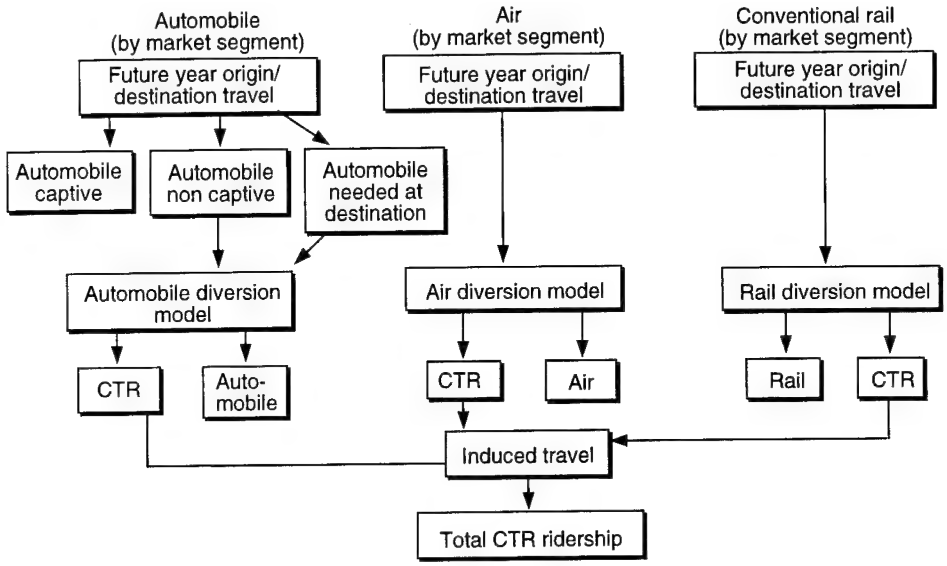


Figure E3.4.2-1. Market Share Diversion Model

values of time indicate the level of sensitivity of the travelers to the potential time savings that can be derived from selecting the new mode. As expected, the values of line-haul time for air travelers are higher than for auto travelers, and both these values are much higher than those that were estimated for conventional rail and intercity bus travelers[4]. Line-haul time savings on the high-speed mode are more important to air travelers than they are to auto travelers, and much more important than they are to conventional rail and bus travelers. This means that current bus and rail travelers are relatively much more sensitive to price differences between modes than they are to time differences and, as a result, much less likely to be diverted to a new high-speed mode such as CTR.

As expected, the values of line-haul time for business travelers are higher than for non-business travelers currently traveling on the same mode (figure E3.4.2-2). The value of non-business line-haul time is between one-half and two-thirds the value of business line-haul time, depending on the market segment. Bus travelers have the lowest values of time.

CTR was assumed to be regarded by travelers as equal to turboprops in amenities, comfort, and safety. This implies that the mode preference for CTR compared to turboprop aircraft is zero. Mode preference is defined as the amount a traveler would prefer one mode over another if their travel time, cost and frequency were equal. Travelers were assumed to have a mode preference for jet travel over both CTR and turboprop. At an average trip length of approximately 200 miles, the mode

Trip Purpose	Mode	Line-Haul Time	Access/ Egress Time	Wait Time
Business	Local air	50.77	56.36	29.23
	Connect air	34.28	N/A	69.42
	Auto	26.19	39.29	17.46
	Rail	15.65	38.73	18.78
	Bus	10.30	37.27	20.60
Non-business	Local air	27.29	31.80	18.19
	Connect air	24.67	N/A	55.00
	Auto	17.18	25.76	11.45
	Rail	9.95	26.35	11.94
	Bus	5.22	15.66	10.44

Source: Charles River Associates

Figure E3.4.2-2 Implied Values of Time Per Hour by Mode and Trip Purpose (In Dollars)

[4] The value of time generally is a function of the traveler's usage rate. As such, the observed differences relate to the higher incomes of air travelers.

preference is equivalent to $18.00 for business travelers and $15.00 for non-business travelers. The value of the mode preference constant increases with trip distance, so that at 500 miles the preference is one-third higher than at 200 miles (i.e., $24 for business and $20 for non-business travelers).

E3.4.3 CTR Carrier Financial Performance Model

The CTR Carrier Financial Performance Model estimates passenger demand, service characteristics, and costs of CTR operations specific to vertiport pairs. Each vertiport pair is considered an individual market. A group of vertiport pairs forms a vertiport system. CTR service characteristics (i.e., frequency and headway) are optimized given estimates of passenger demand. Finally, CTR cost measures are derived as a function of the demand and service characteristics.

Parameters allow the model to test various assumptions such as seat capacity (e.g., 19 or 40 seats), load factors, CTR purchase price, and labor costs. All costs are expressed in 1994 dollars. A steady state operation is assumed. There is no amortization of start-up costs of operations or costs associated with vertiport construction. These are considered later in this analysis. The number of CTR aircraft required is determined as a function of the calculated flight time for each vertiport pair and the assumed annual CTR utilization rate.

Cost parameters have been empirically determined using data from airline operating costs reported for DOT (reference 9). Direct operating costs vary with changes in block time and/or stage length. Indirect passenger operating costs generally vary with the number of passengers. Indirect aircraft operating costs vary with the number of aircraft required.

The major cost categories are:

- *Annualized Aircraft Ownership Costs*

Based on a manufacturer estimate of CTR purchase price augmented by an industry standard requirement for 15 percent initial spare parts. The CTR sale price estimate of $17 to $20 million assumes significant manufacturing efficiencies and spreading development costs over total sales of 500 aircraft. The operator discounted cash flow analysis in Chapter E7 of this technical supplement assumes that the operator buys CTRs when needed and replaces them after 15 years.

- *Maintenance Costs*

Estimated by the manufacturer from preliminary CTR design specifications. Average CTR maintenance requirements of approximately $500 per block hour are 20 to 30 percent higher than comparable turboprop maintenance costs due to added complexity of some CTR components.

- *Commissions to Travel Agents*

Assumed to be 8 percent of revenues. Conventional airline commission fees average from 6.5 percent for Southwest Airlines to over 10 percent of revenues for full-service operations.

- *Landing Fees at Vertiports and Airports*

Estimated to be approximately $3.00 per 1,000-pound maximum gross weight, or approximately $125 per CTR landing. This level of landing fees is roughly sufficient to offset vertiport operating and annualized capital costs in the Northeast corridor. Typical airport landing fees are somewhat lower at major air terminals.

- *Fuel Costs*

Based on manufacturer fuel consumption estimates using advanced engines. CTR fuel usage rates per seat-mile are projected to be in the mid-range of newer turboprop aircraft, but approximately 30 percent less efficient based on fuel consumption per seat mile than a typical fixed-wing aircraft such as the Boeing 737-300. Aviation fuel costs are assumed to rise from current levels of $0.60 per gallon at the rate of inflation.

Other indirect cost items are estimated from operational cost data derived from a conventional airline shuttle operation adjusted for the aircraft size and characteristics of projected CTR operations and include:

- *Cabin and Flight Crew Costs*

Two pilots and one flight attendant are required for each 40-passenger CTR. Pilot and flight attendant unit costs per block hour are $57.50 and $30.21 in 1993 dollars respectively, including fringe benefits.

- *Aircraft Handling and Communications*

These costs include ground property and equipment, communications and control, and ground handling costs. Ground and property costs are proportional to maximum landing weight. Communications and control costs are 1.37 cents per mile. Ground handling costs are $46.30 per flight.

- *Passenger and Baggage Handling*

Passenger and baggage handling costs are estimated to be $3.29 and $2.22 per passenger, respectively.

- *Sales and Advertising*

Sales costs include labor for reservation and sales personnel at $2.35 per passenger. Advertising and publicity costs of approximately $0.70 per passenger are a function of both the number of passengers and stage length.

- *Liability Insurance*

This cost is an exponential function of the number of passengers and stage length. It excludes hull insurance which is assumed to be included in aircraft leasing terms.

- *General and Administrative Costs*

General and administrative (G&A) costs are passenger and aircraft related. Aircraft G&A is estimated at $0.23 per mile flown. Passenger G&A is $0.32 per passenger mile.

- *CTR Operator Profits*

Profitability and return on investment are calculated using a discounted cash flow model in Chapter E7 of this technical supplement.

Vertiport-specific operating activity measures were calculated. These can be used to normalize CTR total or individual costs for comparisons with those of existing airlines. Such measures include per-passenger and available seat mile (ASM) costs. Operating activity measures consist of number of passengers, flights, headways, airborne and block hours, miles flown, gallons of fuel, and operational and backup aircraft required. However, such comparisons depend on the assumptions about the productivity of CTR compared to conventional air.

The mode choice model uses calculated CTR costs, including a margin for operator profit. No costs or profits are calculated for the other modes. Rather, the model assumes that the observed fares for rail and conventional air are sufficient to recover operating and investment costs, including a normal profit. Because these data were taken from a period where airline and rail service lost considerable sums of money, the calculated diversion rates for CTR are likely to be conservative. Alternatively, these assumptions provide a margin to offset some of the uncertainty about CTR costs.

E3.4.4 Vertiport Cost Model

Vertiport costs are derived from elemental design criteria for a set of generalized vertiport layouts which might be located in city centers and suburban locations. The types of vertiports for which different design specifications and cost estimates are derived include: (1) city-center on piers and elevated, (2) suburban elevated and on ground, and (3) at airports. For each vertiport type, different cost estimates are developed depending on the number of CTR operations expected at each facility. Larger volumes of CTR passengers result in the need for additional gates and terminal areas. It is estimated that as many as 1.1 million CTR passengers could be handled annually at each vertiport.

The model was developed from data contained primarily in two reports: "Vertiport Design Characteristics," by Systems Control Technology (SCT), and the "FAA Advisory Circular on Vertiport Designs." Regional construction and land acquisition cost differences are determined by use of the Means construction cost index.

CTR vertiport costs are estimated taking into account unit costs and quantities of the following airside and landside components:

- TLOFs
- Final take-off and landing areas (FATO) which surround TLOFs
- Taxiways between TLOFs and from TLOFs to gates
- Aprons and jetways
- Lighting and marking equipment
- Fueling, snow removal, fire fighting and rescue (ARFF) equipment and facilities
- Land, fencing, and site work
- Piers
- Terminals
- Auto parking facilities.

Costs for loading bridges similar to jetways, a separate CTR maintenance facility, and ATC capital costs are also included. The ATC costs include on-vertiport costs for towers if needed, landing systems, and flight service facilities. Vertiport costs for planning, environmental impact statements, and noise abatement costs are not included, although the model does include a 25 percent charge for project management and contingencies.

Sensitivity analysis can be performed by varying assumptions about individual cost elements (e.g., land acquisition costs) or vertiport design features (e.g., number and type of auto parking spaces provided).

E3.4.5 Delay Reduction Benefits Model

The National Airspace System Performance Analysis Capability (NASPAC) Simulation Modeling System (SMS) was used to analyze the effects of CTR service on airport delays in the year 2010. The analysis made the following assumptions:

- Domestic CTR demand would be 16 million passengers, a level consistent with full CTR service to origin-to-destination and transfer passengers between major metropolitan areas and to outlying feeder airports.
- Projected airport capacity improvements scheduled for completion by 2005 would proceed as planned.
- Airline seats would be replaced one-for-one by CTR seats.
- Airport traffic levels and delays in 2010 would either stay the same as current levels and delays or increase in accordance with passenger demand, as modeled in Chapter E4 of this technical supplement and FAA Long-Term Forecasts of airplane size and relative split between jet and commuter aircraft.

The NASPAC SMS requires data on air traffic, airport capacities, the capacities of other ATC resources (e.g., fixes and sectors), and weather. The data on airport and ATC resource capacities were obtained from FAA and include projected airport improvements. Weather was modelled by including six representative "standard days" that represent a typical year of weather.

The potential delay reduction benefits of CTR were analyzed under two scenarios about future traffic levels and delay levels resulting from non-CTR aircraft operations. These are:

- The projected levels of 2010 CTR activity as reported in Chapter E4 of this technical supplement were assumed to apply to the 1993 level of non-CTR flights and delays.
- The projected levels of 2010 CTR operations were assumed to apply to projected levels of traffic and delay in the year 2010.

As such, the analysis provides a range of potential delay savings which could accrue if CTRs were to replace certain existing airplane operations.

The baseline CTR scenarios assume that CTR service is available and serves 16 million passengers. A separate market study determined which fixed-wing flights would be replaced by CTR service, and these flights were removed from the NASPAC SMS. The removal of CTR flights is based on the assumption that CTR flights do not interact with fixed-wing flights either at the terminal or en route in the ATC environment. This assumption was tested in supporting studies, as

discussed in Chapter E5 of this technical supplement. Baseline CTR scenarios were estimated for both constant and increasing air traffic levels. Since some flights were removed, the baseline CTR scenarios show a reduction in delay from the "without CTR scenarios".

The NASPAC SMS is an event-step simulation model. It models aircraft as they move through the national airspace system (reference 10). The model follows each flight through the steps of pushback from the departure gate, take-off, fix crossing, en route flow restriction crossing, en route sector crossing, landing, and arrival at the destination gate. The maximum capacities of airports and other ATC resources are inputs to the NASPAC SMS. As the model runs, it updates these capacities dynamically to account for changing weather conditions and air traffic patterns. The model also incorporates the effects of ground delay programs, but individual airport elements such as gates, taxiways, and runways are not modelled explicitly.

The principal outputs of the NASPAC SMS are the throughput and delay at each airport, and total throughput and delay in the national airspace system. Two types of delay are reported. Technical delay occurs when an aircraft must wait to use an ATC resource. For example, an aircraft that had to wait for take-off or landing clearance would experience technical delay. Effective arrival delay measures the difference between the actual and scheduled times of arrival. A technical delay can cause an effective arrival delay, but effective arrival delays may also be caused by a ripple effect from delays earlier in the day. Thus, a technical delay on the first leg of a two-leg flight could cause an effective arrival delay on the second leg. Effective arrival delay is of greater concern to passengers because it can result in missed connections.

A module of the NASPAC SMS provides outputs on the costs of delays. For airlines, the costs are based on the sum of estimated airborne and ground holding costs for aircraft experiencing technical delays. For passengers, the costs are based on the value of lost time as a result of effective arrival delays.

E3.4.6 Energy and Emissions Model

Estimates of energy and emission impacts are based on changes in modal demand and access/egress travel times, modal energy intensities, and emissions rates. Energy and emissions factors are assumed for typical jet and turboprop aircraft, and likely CTR engine capabilities.

The effects of the introduction of CTR on energy usage and emissions amounts were calculated for the four proposed corridors: Northeast, Midwest, West Coast, and Southwest. Energy and emissions amounts were calculated from estimated demand data for the specified corridors in the year 2010. The demand data consisted of passenger trips and passenger miles for the existing modes of transportation (i.e., jet, turboprop, auto, and rail), and for CTR.

Energy amounts were calculated for the "before" and "after" scenarios for the four corridors. The difference between the scenarios was the calculated effect of CTR service on energy usage. Energy factors for the various modes of transportation in the year 2010 were derived from different sources. Auto energy intensity was computed from Environmental Protection Agency (EPA) data while diesel and electric train energy values were calculated using a train performance simulation. Jet, turboprop, and CTR energy utilization were determined from data supplied by the manufacturer.

Dollar valuations were calculated for the energy increases. Projected fuel and electricity costs for the year 2010 were determined using the Energy Information Administration/Annual Energy Outlook 1992. Airplane fuel was assumed to cost $0.60 per gallon.

The effects of CTR service on emissions were also determined for the four corridors. As in the energy calculations, "before" and "after" scenarios were calculated to determine the emissions effects. The three emissions considered were carbon monoxide (CO), hydrocarbons (HC) and oxides of nitrogen. These emissions were included for their negative impacts on air quality and personal health.

While other emissions also have deleterious impacts on society (such as SOx), the emissions listed above are the primary emissions for jets, turboprops, and CTR and are the only ones reported by jet and turboprop manufacturers.

Emissions factors were determined for each of the various modes of transportation. Jet emission factors were calculated using the emission rates for a Boeing 737-300 aircraft and averaging them over estimated flight profiles for the city-pairs in the corridors. Turboprop emission values were determined in a similar manner, but assuming that a SAAB 2000 would be typical of turboprop aircraft after 2010. CTR emission factors were determined by constructing flight profiles consistent with CTR2000 assumed capabilities and projected emission rates for the Allison T406 engine. This is the advanced, low-emission engine that could be used on the first CTR aircraft.

Auto and diesel train emission values were determined using EPA emission factors. Electric train emission characteristics were determined by Argonne National Laboratory.

Dollar valuations for the emissions changes were calculated using a control cost methodology developed by Argonne National Laboratory (reference 11). The dollar valuations for HC, CO and oxides of nitrogen emissions are city-specific and are based on estimates of the technology costs of bringing each area into compliance with air quality standards. Specific control cost valuations were used when available; interpolated approximate values were used in other cases. Because emissions that occur at cruising altitudes do not contribute to deterioration of metropolitan area air quality, the dollar value of these airborne emissions were not evaluated. Thus, the value of emissions were calculated only for the taxi-in, taxi-out, ascent and descent phases of flight. Note that the total tonnage of emissions were calculated for phases of flight, as some airborne emissions contribute to global warming. Unfortunately, a reliable method for evaluating the social cost of these emissions was not available.

E3.5 Risks and Uncertainties

The analysis of the commercial viability of U.S. operation of CTRs in airline service is founded on many fundamental assumptions, including the state of the intercity transportation market in the early part of the 21st century after CTR introduction to commercial service, and the characteristics and costs of CTR aircraft, air traffic control services, and CTR and other airline operators. Because these assumptions are made about years well into the future, there is considerable uncertainty and risk surrounding the accuracy of these predictions. Some of these risks have been examined through sensitivity analysis, others are less subject to quantification. Listed below are the major areas of risk with a brief discussion of their possible impacts on CTR viability.

- *Conventional Airline Price Structure*

CTR operational viability has been found to be highly dependent on the level of conventional airline prices. Recent trends indicate that the spread of low-cost airlines into new markets and the more frequent use of contracted fares might lead to reductions in overall airfares in future years. These trends were not applied to the future CTR operating concept. The need to replace old aircraft and the added costs of doing business in more congested airspace might result in increases in airline costs and increases in future airfares. On the other hand, the observed fares for conventional air and rail modes were taken from a period when the airlines incurred substantial losses and Amtrak was heavily subsidized.

- *Airline Competitive Response*

In addition to variation in airline fares due to changing costs, there are numerous possible responses by the airlines to new CTR competition. These competitive responses are not well understood. Fare reductions to keep market share are certainly possible, but so are changes in amenities, frequent flyer inducements, and yield management approaches. Variability in future conventional airline fares is an important uncertainty regarding CTR viability.

• *Siting of Vertiports*

Vertiport siting is an extremely important issue for CTR viability. Noise and safety concerns, as well as locating suitable tracts of land in downtown and suburban areas, are likely to cause considerable local controversy and possibly severe restrictions on vertiport siting. Limiting the number and/or desirability of vertiport locations has been estimated to lead to as much as a one-third reduction in CTR ridership. In the extreme, CTR service would not be viable if suitable vertiport sites were not available. However, in the foreseeable future, vertiports are the only landing sites likely to be built within 20 miles of the center of any major city.

• *Initial Start-up Costs*

Helicopter and conventional airline operators indicate that costs for providing CTR service would likely be much higher during the initial months of regular service operation. Reasons for this include extra training and certification costs, operational break-in inefficiencies, and uncertain vehicle reliability. Also during this initial period, CTR demand might fluctuate around expected steady-state predictions. Start-up costs are included in the operator discounted cash flow analysis in Chapter E7 of this technical supplement. Potential CTR operators must plan to have sufficient financial reserves to make it beyond this less profitable start-up period.

• *Future Air Travel Demand*

The projections of future air travel depend on forecasts of regional increases in population and aggregate income, as well as the variation in future airline price levels. Although the Base Case air demand estimates are consistent with FAA long-term national forecasts, there is considerable inherent variability in these forecasts when extrapolated 30 or 40 years into the future.

One meaningful added dimension involves the projection of connecting air service. Note that this type of air service is of great importance, especially in many Midwest markets. A good deal of this service is produced as a consequence of the current airline hubbing structure. If hub locations were to change significantly or the airlines reverted to more direct flight itineraries, a significant share of potential CTR service might disappear. For this reason, it is prudent to put less weight on projections of CTR demand diverted from existing connecting air service.

• *CTR Operational Efficiency*

The downside risks to CTR profitability due to CTR operational constraints need to be considered. CTR operations are expected to draw riders mostly from the business community. Because business travel is more concentrated over fewer hours of the day and days of the week than non-business travel, it will probably be more difficult for a CTR operator to consistently achieve both high load factors and high aircraft utilization. Deterioration in either of these areas results in significant increases in projected CTR operational costs and, consequently, reduces projected ridership.

• *CTR Sales Price*

Potential CTR manufacturers assumed a price range for a CTR aircraft of between $17 and $20 million in 1993 dollars. Their analysis assumed sizeable manufacturing efficiencies worth over $4 million per aircraft. Boeing and Bell claim that recent manufacturing technology innovations (e.g., in composite materials fabrication and use of computer-controlled machine tools) have led to significant cost savings in the production of both aircraft and helicopters. In addition, CTR selling price projections are based on amortization of $1.2 billion in start-up costs over the eventual sale of 500 CTRs worldwide. If these sales targets are not met, the CTR manufacturer profits would be lower. On the other hand, if worldwide sales are greater than the assumed 500 aircraft, CTR manufacturer profits would be higher than projected.

• *CTR Line-haul Travel Time*

CTR line-haul times are estimated to be faster than turboprop and competitive with many existing scheduled jet aircraft travel times, especially for markets closer than 300 miles apart. This is because CTRs are assumed to fly more direct routes between vertiports than conventional aircraft do

between airports. In addition, CTRs are assumed not to be subject to terminal area delays that lengthen conventional air travel times in many congested metropolitan areas. The validity of these assumptions depends on favorable incorporation of CTRs into the ATC system in ways that maximize CTR capabilities. If CTR operations are wedged into an ATC system that is designed only to meet the needs of conventional air services, many CTR inherent advantages will not be realized.

• *Safety*

An early CTR accident could have significant long-term negative impacts on traveler perceptions of CTR safety. A base of safe operation of tiltrotor may be needed to assure passengers that the CTR is safe.

• *Risk Compounding*

CTR commercial success is particularly vulnerable to failure due to risk compounding. "Success" requires that a large number of unknowns be resolved in favor of CTR, while a negative resolution of only one or two unknowns could result in failure.

E4.0 Commercial Viability of CTR Corridors

E4.1 Demand and Revenues

E4.1.1 Introduction

The analysis of the commercial viability of civil tiltrotor (CTR) found that CTR service introduced in the first or second decade of the next century could attract sizable ridership in many domestic markets. CTR service is more likely to be financially viable in the Northeast and some Midwest markets than in the West Coast and Southwest corridors due to higher prevailing airfares.

The level of CTR passenger demand depends on its relative advantage or disadvantage over conventional air travel and other existing modes in overall travel time and cost. Total CTR travel time, including line-haul, access/egress, and terminal times, is always lower than turboprop travel times and is significantly lower than jet travel times in all but the longest markets (figure E4.1.1-1).

CTR has an advantage in access/egress time over conventional air travel because vertiport locations are expected to be more convenient. Downtown and suburban vertiport sites are closer to desired intercity passenger trip endpoints than existing airport locations even when there are multiple airports in a metropolitan area.

Vertiports have an advantage in terminal time requirements because they will be much smaller than existing airports. Vertiports will be designed to serve fewer intercity passengers because they serve fewer markets. They also will be limited in size due to environmental concerns and a desire to provide multiple vertiport sites in larger metropolitan areas.

CTR line-haul times are estimated to be faster than turboprop flights for all potential CTR markets and are competitive with existing scheduled jet times for many markets, especially those closer than 300 miles apart.

The cruise speed of the 40-passenger CTR, 360 miles per hour, is faster than most turboprop aircraft. The CTR line-haul time difference compared to jets is not as large as it would appear in shorter trip-length markets where cruise time is limited to a minor part of total trip line-haul time. CTR distances flown may also be shorter due to less circuitous routings.

CTRs are assumed not to be subject to terminal area delays that lengthen conventional air travel times in many congested metropolitan areas. Analysis has shown that CTRs could proceed more directly to downtown and on-airport vertiports than conventional aircraft can approach airports because of its vertical flight capability (reference 12).

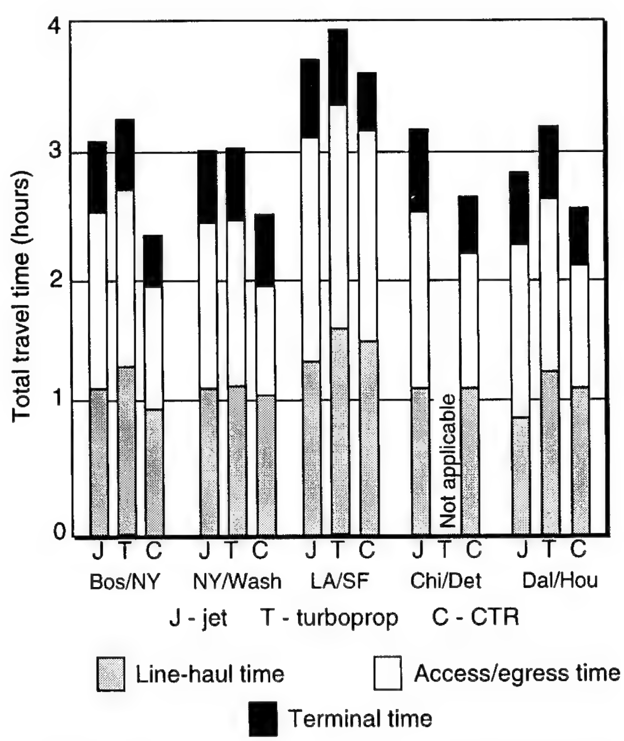


Figure E4.1.1-1 Jet, Turboprop, and CTR Total Travel Times in Key City Pairs

For most potential markets, total out-of-pocket passenger trip costs on CTR are expected to be higher than for conventional air. Total travel costs consist of fares and access/egress expenses (e.g., auto out-of-pocket costs, car rental or taxi fees, and parking charges). Access/egress expenses are projected to be slightly smaller for CTR passengers because, in general, CTR vertiports are assumed to be located closer to the trip origination and destination point than existing airports. However, CTR fares must be set substantially higher than for similar conventional air trips to cover higher CTR acquisition and operating costs. CTR attracts substantial demand because its total travel costs, including the value of travel time, is less than that of other modes for many passengers.

E4.1.2 Diversion Rates

The combination of travel time and cost factors results in a pattern of CTR diversions from conventional air that varies from market to market as shown in figure E4.1.2-1. The most important determinants of CTR diversion rate are the level of existing airfares and the suitability of vertiport locations.

Corridor	Percent Diverted From Air	Typical Fare Premium (percentage)	Typical Fare Premium for Major Markets (dollars)
Northeast	20	45	51
Midwest	12	15 to 125	69
West Coast	4	135	115
Southwest	6	130	86
Overall	11		

Figure E4.1.2-1 CTR Diversion Rates for Vertiport-to-Vertiport and Feeder Routes in 2010

Figure E4.1.2-2 shows the 1992 average fares per mile of the three largest passenger volume markets in each corridor. Clearly, there are major differences in fare levels among these corridors and among individual markets, especially in the Midwest.

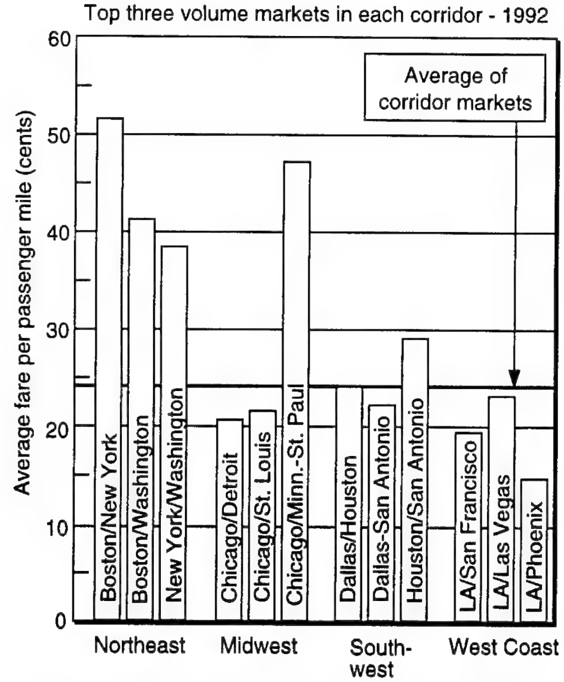


Figure E4.1.2-2. Typical Air Carrier Fares per Mile

The most important influence on diversion rates is the level of conventional airfares. Favorable CTR diversion rates can be realized in city pairs where existing conventional airfares are high, such as the Northeast and some Midwest markets. But in the West Coast and Southwest corridors, where airfares are traditionally low, CTR diversions are much lower.

The opportunity to site vertiports in downtown and other favorable suburban locations is also an important determinant of CTR viability. As noted below in the sensitivity analyses, if less advantageous vertiport sites must be used, CTR demand might drop by as much as one-third.

As shown in figure E4.1.2-3, diversions to CTR service are higher for business travelers because they have higher values of time and will pay

Aircraft Type	Business	Non-Business
Jet	22%	15%
Turboprop	26%	24%

Figure E4.1.2-3 Diversion Rates Origin-to-Destination Travel Northeast in 2010

more in out-of-pocket travel costs to save time. Diversion rates are also higher for former turboprop passengers because CTR has a time advantage relative to these slower aircraft. In addition, the model assumes a small passenger preference toward jets, but no absolute preference between turboprops and CTRs, except as related to aircraft size and service frequency[5].

In general, diversion rates for air origin-to-destination (O/D) travel are higher than for connecting or transfer travel. This is primarily due to lower values of time for air-transfer passengers. However, there are also smaller access time advantages because vertiports would only be at one end of the trip, and there is assumed to be more difficult connections between terminals for CTR transfer passengers.

The expected number of passengers diverted to CTR service depends on the base level of existing air travel (figure E4.1.2-4) and the projected CTR diversion rate. City-pairs with significant amounts of conventional air travel will be more likely to support CTR service because they will be better candidates for one or more vertiports and more likely to justify a minimum level of CTR flights.

Corridor	O/D Traffic	Feeder Traffic	Transfer Traffic
Northeast	5.4	10.8	6.6
Midwest	7.2	8.4	21.2
West Coast	18.4	5.9	5.7
Southwest	3.2	6.7	6.9

NOTES: • Annual passengers in millions; one-way trips
• Includes only cities expected to have vertiports

Figure E4.1.2-4 Existing Air Passengers by Corridor in 1992

E4.1.3 Passenger Trip Projections

The following estimates of future CTR travel are based on forecasts of conventional air travel that are consistent with Federal Aviation Administration (FAA) long-term forecasts, assuming no major changes in airfares from 1994 levels. The assumption of constant real airfares would limit the overall size of the projected air travel market compared to an assumption of declining real airfares. CTR travel estimates have been broken into three categories:

- *Vertiport to Vertiport*

CTR vertiport-to-vertiport travel is O/D travel between major metropolitan areas (figure E4.1.3-1) served by one or more downtown and suburban vertiport locations.

Northeast	Midwest	West Coast	Southwest
Boston New York Washington Philadelphia	Chicago Detroit Cleveland Pittsburgh Cincinnati Minneapolis	San Diego Los Angeles San Francisco Las Vegas	Dallas Houston

Figure E4.1.3-1 Major Metropolitan Areas

- *Feeder*

CTR feeder travel is between vertiports in major metropolitan areas and uncongested airports within 500 miles. Airport vertiports are not assumed at the feeder airport end of the flight. Note that inclusion of vertiports at feeder airports might increase diversion rates a few percent. Only feeder markets that could generate two round-trip CTR flights per day by 2010 are included in the analysis.

- *Transfer*

CTR transfer passenger trip estimates include connecting passengers diverted from longer trips where one leg is either a vertiport-to-vertiport segment or a feeder segment. It is assumed that these types of diversions could only occur where a vertiport is collocated at a metropolitan area airport.

CTR travel to feeder airports is an important component in the Northeast and Midwest, and diverted transfer travel contributes substantially to

[5] In future research, it may be productive to try to determine how the turboprop mode preference penalty varies with aircraft size.

overall CTR ridership in the Midwest. However, a substantial portion of connecting air traffic is a by-product of current hub-based airline flight patterns. Because hubbing practices are volatile and the future sites of airline hubs are uncertain, the estimates of CTR travel diverted from connecting air passenger traffic is much less certain than estimates made regarding air O/D travelers.

Figure E4.1.3-2 shows total annual CTR enplanement trip projections for the year 2010 for each corridor and trip type. Figure E4.1.3-3 shows that most of the projected CTR trips result from diversions of existing passengers.

E4.1.4 Passenger Profile

Most CTR passengers are time-sensitive business travelers, but even with premium fares, CTR service is able to attract a reasonable number of non-business, or pleasure, travelers. On O/D trip itineraries, approximately 35 percent of CTR travel is estimated to be for non-business trip purposes. The percentage of non-business travel is projected to be substantially higher on trips involving a transfer between conventional air and CTR as shown in figure E4.1.4-1. The percentage of existing air business travel in each market is derived from data developed in national surveys, including

Corridor	Vertiport-to-Vertiport	Feeder	Transfer	Total
Northeast	3.4	2.5	1.0	6.9
Midwest	0.7	2.8	3.5	7.0
West Coast	1.3	0.2	0.3	1.8
Southwest	0.3	0.0	0.1	0.4
Total	**5.7**	**5.5**	**4.9**	**16.1**

Figure E4.1.3-2 Annual CTR Enplanement Trip Projections in 2010 (In Millions)

Corridor	Without CTR	With CTR **		
	Conventional Air	CTR *	Conventional Air	Total
Northeast	27.1	5.7	21.8	27.4
Midwest	25.3	3.3	22.2	25.5
West Coast	40.4	1.5	38.9	40.4
Southwest	4.6	0.3	4.3	4.6
Total	**97.4**	**10.8**	**87.2**	**98.0**

* Air diversions only; an extra 0.4 million CTR trips would be diverted from auto and rail

** Vertiport-to-vertiport and feeder services; transfer not included

Figure E4.1.3-3 Estimates of 2010 Air Travel (Origin-Destination) For Travel Suitable for CTR Services, With and Without CTR Services Available (Millions of Trips)

Corridor	Origin-to-Destination Between Vertiports	Feeder	Transfer
Northeast	63	60	25
Midwest	66	61	35
West Coast	79	N/A	N/A
Southwest	81	N/A	N/A

Note: Estimates for West Coast and Southwest feeder markets and for transfer passengers are unreliable due to small numbers and not reported

Figure E4.1.4-1 Estimates of the Percentage of CTR Business Travel in 2010

Air Transport Association and Travel Data Center surveys as well as the various Nationwide Personal Transportation Surveys. These indicate that business air travel accounts for roughly 50 percent of all air trips. The surveys also show a marked lower proportion of business travel as travel distances increase. These factors account for a distinct business orientation to projected CTR ridership, especially in shorter distance markets.

The higher percentages of CTR business travelers predicted for the West Coast and Southwest corridors reflect the much higher fare premiums that would need to be charged in these traditional low-fare markets for CTR operations to break even. As such, only those passengers who value their time very highly are diverted to CTR.

Nearly all CTR passengers are former air travelers. Diversions from auto and rail modes are insignificant in most markets. CTR service is projected to attain modest shares of auto and rail passengers only when CTR fares are assumed to be at least 10 to 20 percent below baseline levels (see paragraph E4.3.1). This is consistent with prior expectations because those passengers who value their time most have already chosen conventional air over the surface modes.

Although CTR competes more successfully with turboprop operations, most CTR passengers are former jet passengers. This is because a very high percentage of existing air passengers, in markets likely to be served by CTRs, currently use available jet services.

Figure E4.1.4-2 shows that increases in overall intercity travel in years beyond 2010 will result in increased use of CTR. Additional diversions will accrue to CTR because volume increases based on population growth will lead to increased CTR flight frequency and, potentially, a requirement for additional metropolitan area vertiports. The overall growth in CTR patronage between 2010 and 2030 is estimated to be approximately 45 percent.

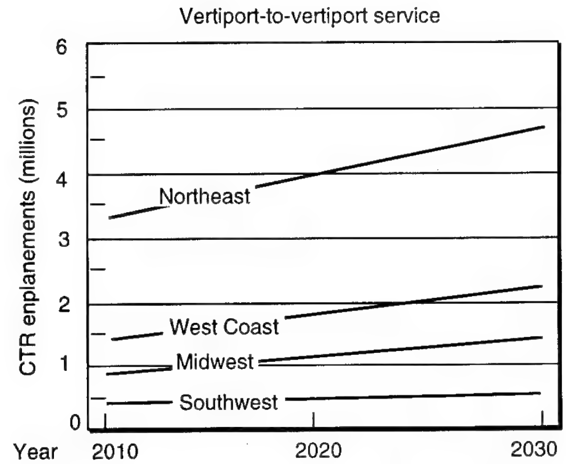


Figure E4.1.4-2 Annual CTR Enplanements by Corridor

E4.1.5 CTR Aircraft and Vertiport Requirements

The number of CTR aircraft required to meet projected passenger demand is estimated directly from assumptions about average load factors and aircraft utilization (i.e., flight hours per year), and estimates of CTR travel times and passengers carried (figure E4.1.5-1).

The number of CTR aircraft required in all four market areas investigated ranges from 126 for vertiport-to-vertiport travel in 2010, to 326 if feeder and connecting passengers are included. These projected CTR aircraft requirements are consistent with the vehicle units suggested by Boeing/Bell for calculating initial CTR aircraft costs.

Corridor	Vertiport-to-Vertiport	Feeder	Transfer	Total
Northeast	67	60	22	149
Midwest	18	47	64	129
West Coast	35	2	4	41
Southwest	6	0	1	7
Total	**126**	**109**	**91**	**326**

Figure E4.1.5-1 Estimated CTR Aircraft Requirements in Four Major Corridors in 2010

The evaluation assumes that the number of vertiports that will be provided in each metropolitan area will be sufficient to meet projected CTR passenger demand. The number of vertiports are set to satisfy demand requirements for the year 2020, the midpoint of the analysis period. It is assumed that vertiports can be located in optimal locations with respect to passenger demand and that land adequate for one million passengers per year, approximately 10 to 30 acres, will be available for downtown and suburban vertiports. In most cities, only one vertiport will be required.

Requirements for CTR aircraft are expected to increase over time as passenger demand for CTR services expands. Figure E4.1.5-2 shows that estimated CTR aircraft requirements in the four U.S. corridors studied increase from 326 units in 2010 to 454 units in 2030.

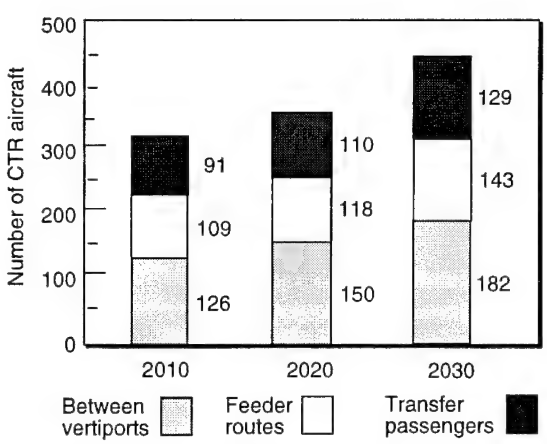


Figure E4.1.5-2 Estimated CTR Aircraft Requirements for Four U.S. Corridors, 2010 to 2030

E4.1.6 CTR Fare Premiums

The analysis assumes that, to be commercially viable, CTR operators will need to set fares at levels high enough to completely cover baseline CTR operating and costs, and provide the operator with a return on investment[6]. CTR operating costs were estimated using national averages for many cost categories. In market areas with significant low-fare carrier presence, this practice would lead to high CTR fare premiums over conventional airfares and, as a consequence, relatively low diversion rates from existing air services. Conversely, in markets characterized by high conventional airfares, CTR fare premiums are low and CTR market shares are projected to be reasonably high. It should be noted, however, that the observed fares for conventional air may not cover all operating costs and provide an adequate return for the operator to replenish capital.

In figure E4.1.6-1, CTR fare premiums as a percentage of conventional airfares are shown for a sample of typical city-pair markets in each analysis corridor. The highest CTR fare premiums, approximately 130 percent, occur in the West Coast, Southwest, and a few Midwest markets. These are all markets dominated by Southwest Airlines. In the Northeast and some Midwest markets, required CTR fare premiums are lower (approximately 45 percent), while in other Midwest markets, break-even CTR fares could be set equal to or lower than existing airfares.

CTR diversion rates from conventional air service are higher (e.g., 15 percent to 40 percent) in high conventional airfare markets. They are lower

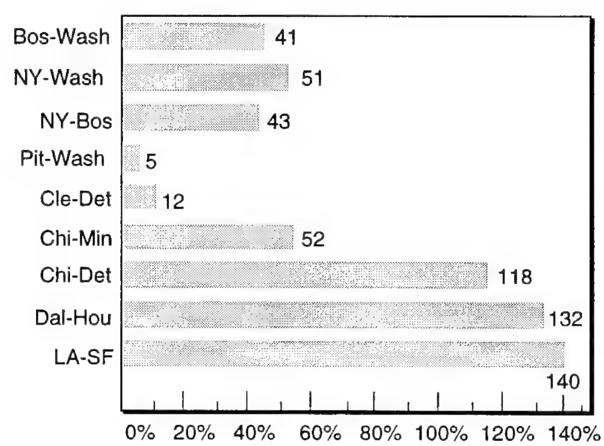


Figure E4.1.6-1 Estimated CTR Fare Premium in Key City Pairs

[6] As noted above, the mode choice model estimates diversions to CTR based on the full price of travel, including airfares, access time and costs, value of travel time, and schedule availability.

(e.g., less than 10 percent) in low-fare markets. Figure E4.1.6-2 shows this trend in business jet travel markets, and also shows that CTR diversion rates fall as the distance between city-pairs increases[7].

CTR fare premiums on an absolute basis are shown in figure E4.1.6-3. The differences between CTR fares and average conventional fares typically range from under $10 in the Northeast to over $100 in low-fare markets. The average absolute fare differences, while significant, are generally less than the differences between quoted full fares and discount fares.

The difference in total costs to CTR and conventional air travelers is reduced somewhat by savings that CTR travelers often will receive in access/egress costs, because many of them will be closer to vertiports than to existing airports. These savings can be significant in individual cases, but averages only a few dollars per trip for two major reasons. Many air access trips have a high fixed component, e.g., parking fees, which is paid no matter how far a traveler is from the air terminal. Also, downtown areas, which are the most likely trip location and site of most vertiports, are diminishing in influence as suburban trip-ends grow in importance. Passengers who divert to CTR pay these higher out-of-pocket costs because they are more than offset by the value of travel time served[8].

E4.2 CTR Operating and Capital Costs

Overall CTR costs per passenger trip were estimated to average $113 ($0.29 per available seat-mile (ASM)) in the Southwest, $115 ($0.29 per ASM) in the Northeast, $125 ($0.27 per ASM) in the Midwest, and $135 ($0.25 per ASM) in the West Coast corridor. These costs are expected to

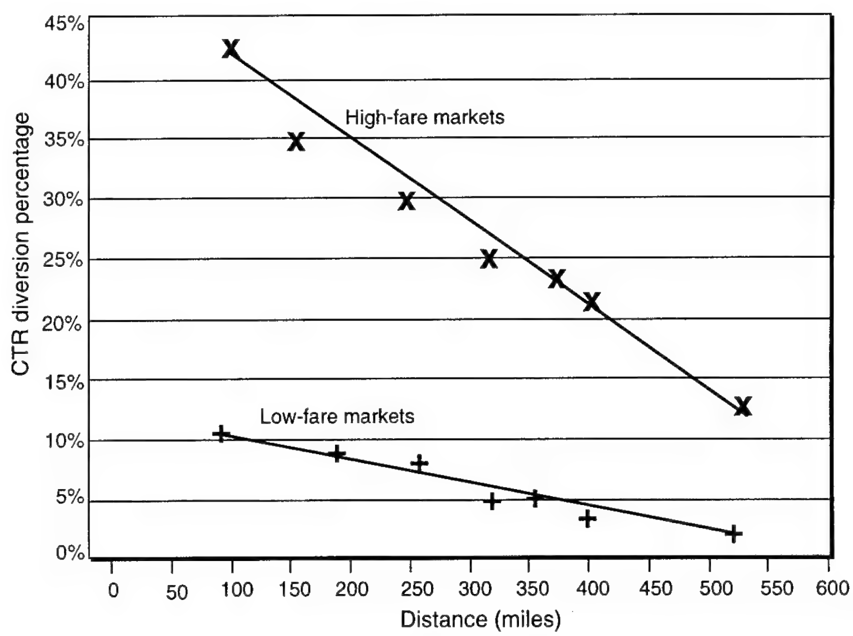


Figure E4.1.6-2. CTR Diversion Percentage Versus Distance for Business Market Segment (Jet Service)

[7] If CTR fares were set below break even levels, CTR operations would result in losses for the operator. In low-cost markets these losses could be substantial. For example, in the West Coast corridor, if a typical high-airfare-market fare premium were charged (i.e., about 30 percent of conventional airfares), CTR operators would be expected to generate only $83 in revenue per one-way passenger trip, but have total costs of about $135 per passenger trip. Lower CTR fares would likely attract many more passengers - the estimated diversion rate in the West Coast corridor would increase from six percent at break even fare premiums to over 45 percent of the conventional air market. However, increased traffic levels would only magnify the CTR operator's losses. In fact, under this scenario, projected CTR operating losses for the West Coast corridor in 2010 were estimated to approach $1 billion.

[8] The Volpe model assumes that access/egress costs are represented by automobile costs and that parking costs are included. The model assumes no difference between parking costs at airports and vertiports. Because many business travelers use taxis, limousines or other commercial access modes, the assumption that access/egress costs are equivalent to automobile costs is likely to understate access cost savings for CTR business travelers.

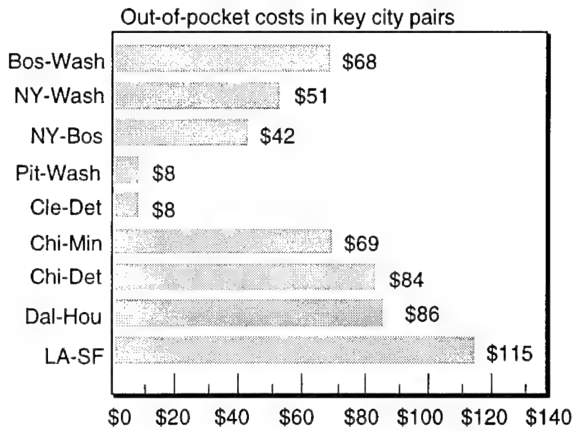


Figure E4.1.6-3 Estimated Fare Differences Between CTR and Air

be significantly higher than for most conventional air carriers (figure E4.2-1). Note that many of the average stage lengths shown in the figure are considerably greater than expected for typical CTR trips. Therefore, the differences between ASM costs for CTR and conventional air service would be less if calculated at equivalent distances.

CTR fares in each city-pair market are set to match total operating and annualized capital costs for an autonomous CTR operation. Fares include the 10 percent airline ticket tax. Together, the cost categories encompass all of the costs that a CTR airline would reasonably face, including administrative charges and modest profit margins. Figure E4.2-2 shows an example of a typical CTR cost breakdown.

There are three main categories of cost: direct, indirect, and ownership. Direct costs consist of crew, block fuel, and maintenance. Indirect costs are passenger and aircraft related. Passenger-related indirect costs consist of amenities, liability insurance, passenger handling, baggage handling, reservation and sales, commissions, advertising and publicity, and passenger-related general and administrative costs. Aircraft-related indirect costs include ground property and equipment, control and communications, landing fees, ground handling, ground fuel, cabin crew, and aircraft-related general and administrative costs. Ownership costs result from the terms of capital leases or purchases

Airline	Cost Per Available Seat-Mile (ASM) ($0.01) *	Average Stage Length (miles)
Small-aircraft, short-haul airlines		
USAir Shuttle	24.3	202
Aloha	21.7	132
Horizon	21.1	170
Mesa (group)	20.2	182
Air Wisconsin	19.3	139
Atlantic Coast	18.5	143
Comair	15.6	152
Atlantic Southeast	13.9	238
Other airlines		
USAir	11.5	537
Midwest Express	11.4	683
Northwest	9.5	850
Alaska Air	9.2	692
TransWorld	9.2	846
American	9.0	1033
United	9.0	1061
Continental	8.2	710
Hawaiian	8.0	291
Reno	7.9	447
Kiwi	7.6	847
Southwest	7.2	388
America West	7.1	676

* Not adjusted for stage length
SOURCE: FAA Quarterly Industry Report, 2/95

Figure 7.5.1-1 Airline Operating Costs Per Available Seat-Mile, Fiscal Year 1994

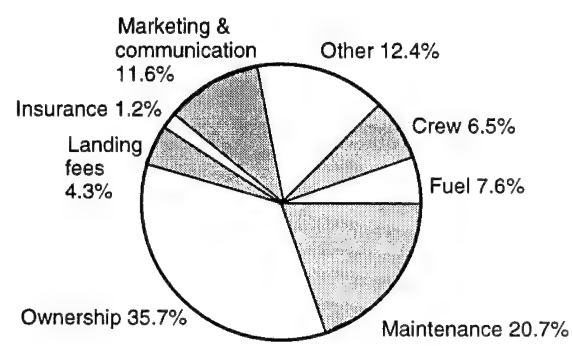


Figure E4.2-2. Northeast Corridor CTR Costs Base Case - 2010

for the number of planes required to meet demand and service levels. Hull insurance is included as part of the leasing agreement.

Although some CTR cost reductions are feasible, it is not likely that overall CTR costs could be reduced below conventional airline costs even if efficiencies similar to those achieved in low-cost airlines were duplicated in CTR operations. The reason that estimated CTR costs are substantially higher than reported costs for conventional air carriers is due primarily to an inherently more expensive design. The breakdown of CTR costs by category indicates that ownership, maintenance, and fuel costs represent approximately 64 percent of total CTR operating costs, with annualized ownership cost representing approximately 36 percent of total CTR costs.

It should be noted that, except for variations due to distance, CTR operating costs were assumed to be similar for all corridors evaluated and unaffected by geographical factors or the cost structure of the CTR operating carrier. If CTR operators were able to emulate the cost reduction and productivity improvements of the most efficient, low-cost airlines[9], then the uniform cost assumption used in the analysis might overestimate costs of CTR operations. Estimated CTR fares might then be closer to airline market fares, with a possibly significant effect on CTR market penetration (see paragraph E4.3)

E4.3 Sensitivity Analysis

Adjustments were made to 1992 airfare data compiled from the actual fares paid by air travelers represented in the Department of Transportation (DOT) Research and Special Programs Administration (RSPA) 10 percent sample of aviation coupons to reflect recent alterations in actual airfares paid in short-haul air markets. One source of these data is the American Express catalog of business airfares for 1992 to 1994. These changes consisted of an overall 15 percent reduction in Northeast airfares, a 30 percent increase in Midwest low-fare markets, and a 30 percent reduction in Midwest high-fare markets. No changes were warranted in West Coast and Southwest corridor fares. The base case assumption is that these adjusted airfares would remain constant in real terms over the analysis period of 2010 to 2030.

The sensitivity analyses were conducted using vertiport-to-vertiport passenger demand estimates.

E4.3.1 Fare Sensitivity

To test the impact of higher or lower future conventional airfares, a sensitivity analysis was conducted in the Northeast where conventional airfares were varied by 15 percent up and down from the base. The positive variation is equivalent to the unadjusted 1992 airfares in that region. The impact of these changes is shown in figure E4.3.1-1. A 15 percent increase in conventional airfares produces a 38 percent increase in projected CTR traffic. A 15 percent reduction in prevailing airfares would lead to a 17 percent reduction in CTR travel estimates. Note that the more pronounced effect of a fare increase is partially due to an assumed extra vertiport needed to handle the addi-

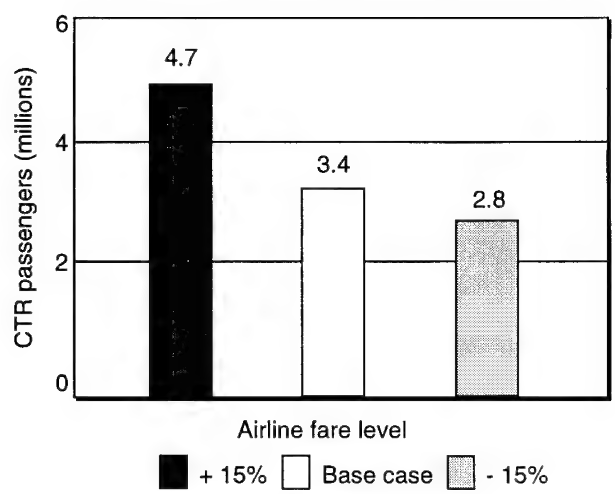


Figure E4.3.1-1 Variation in Airline Fares - Northeast 2010

[9] Much of the cost savings would be expected to be realized in improvements in CTR aircraft and flight crew utilization. For example, Southwest Airlines is able to obtain over 11 flight hours per day from their fleet of aircraft as compared to the industry average of under seven hours per day, and Southwest's pilots average about 25 more flight hours per month than pilots for other airlines. It is unclear how successful a CTR operator would be in duplicating a low-cost carrier's performance (see discussion of Risks and Uncertainties - Section D4.4).

tional CTR traffic in New York. Without the added vertiport, the impact of both positive and negative fare changes would most likely be approximately the same, i.e., plus or minus 17 percent.

E4.3.2 CTR Selling Price Sensitivity

The assumed base case price of a CTR aircraft is \$18.5 million in 1994 dollars. This is in the middle of a range of possible future CTR prices estimated by potential CTR manufacturers. Their analysis assumed sizeable manufacturing efficiencies worth over \$4 million per aircraft and amortization of \$1.2 billion in development costs over the eventual worldwide sale of CTR aircraft[10]. Manufacturers recently have demonstrated significant manufacturing cost savings in the production of civilian and military aircraft models such as the Boeing 777 and the V-22. However, if none of the assumed cost savings materialize, the manufacturers estimate that the CTR selling price could be as high as \$24 million per plane. In addition, deviations in the production rate or in the expected total amount of worldwide sales could significantly impact CTR manufacturing program costs and profitability in either direction.

The impact of higher CTR selling prices is shown in figure E4.3.2-1 for the Northeast corridor in 2010. Similar results would be expected for other corridors or analysis years. Increasing CTR prices to \$20 million reduces demand for CTR service between Northeast vertiports by approximately 10 percent. Reducing CTR prices to \$17 million per unit increased the demand for CTR service by approximately 10 percent.

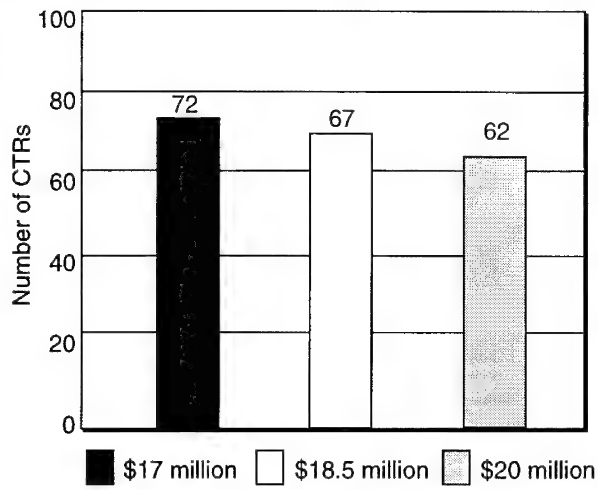


Figure E4.3.2-1 Variation in Aircraft Selling Price - Northeast 2010

E4.3.3 Travel Time Sensitivity

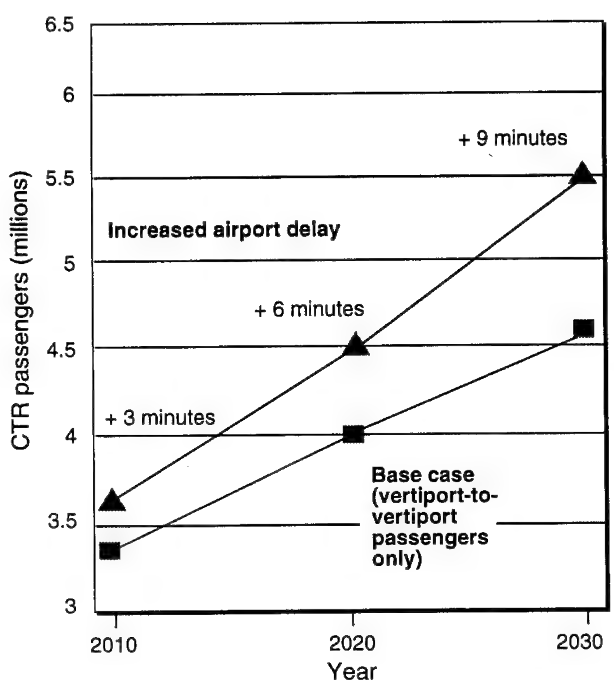
Base case travel times for conventional jet and turboprop air services are calculated from a sample of actual 1993 flights that were tracked by the Enhanced Traffic Management System. These travel times incorporate all congestion-related delays in the existing terminal area and en route air system. CTR travel times are calculated from a flight profile constructed from CTR design specifications and expected air traffic control (ATC) routes. CTR travel times are assumed not to suffer from operational delays in terminal areas.

Travel time variations from base case estimates can be postulated. For fixed-wing air operations, additional delays at crowded airports might be expected to increase overall travel times. The FAA projects increases in the number of conventional air operations at many airports. However, the size and timing of these changes, and their effect on air system delays, are quite uncertain. Construction of new runways, development of new communications, navigation and surveillance technology, or changes in airline operational practices could reduce aviation delays below those levels projected. For example, the introduction of precision runway monitors, automatic dependent surveillance (ADS) using the Global Positioning System (GPS), higher aircraft load factors, and even diversions of passengers to new vehicle types such as high-speed rail and CTRs would all serve to reduce delays, perhaps to levels below those in current FAA projections. On the other hand, the recent trend of substituting smaller turboprop aircraft for larger jet aircraft may have the effect of increasing operations and thereby increasing aircraft delays.

[10] Under scenarios where NASA funds additional research and technology development, manufacturer funded development costs could be reduced to as low as \$1.2 billion.

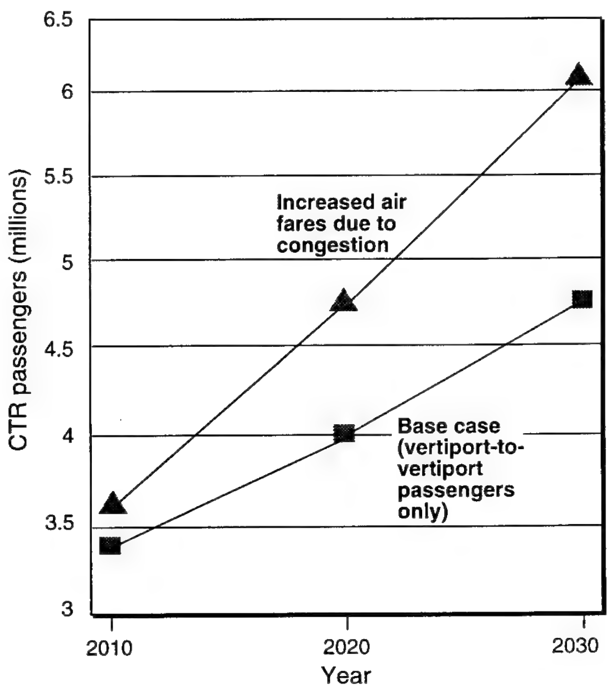
The results of two sensitivity runs that test possible future year variations in conventional air delays are shown in figures E4.3.3-1 and E4.3.3-2. Figure E4.3.3-1 shows the effects of increasing average airport delay by 3 minutes per flight per decade. The current average air delay is estimated by the FAA to be approximately 14 minutes per flight (reference 13). Because CTRs would have an increased travel time advantage under these conditions, estimated CTR usage increases by 10 percent over base case projections. If instead, as shown in figure E4.3.3-2, conventional airfares increased by an amount sufficient to keep future air operations at about the same level as today, CTR patronage would be expected to increase more rapidly.

The results of both positive and negative variation in CTR line haul travel times in the Northeast are summarized in figure E4.3.3-3. Here a 10 percent increase in CTR time results in a 9 percent reduction in overall CTR demand, while a 10 percent reduction in CTR travel time results in a 12 percent increase in CTR patronage.



Note: Average air line-haul times assumed increased by 3 minutes per decade

Figure E4.3.3-1 Increased Airport Delay - Northeast Corridor



Note: Airline fares increased by an amount sufficient to eliminate delay increases

Figure E4.3.3-2 Increased Air Fares - Northeast Corridor

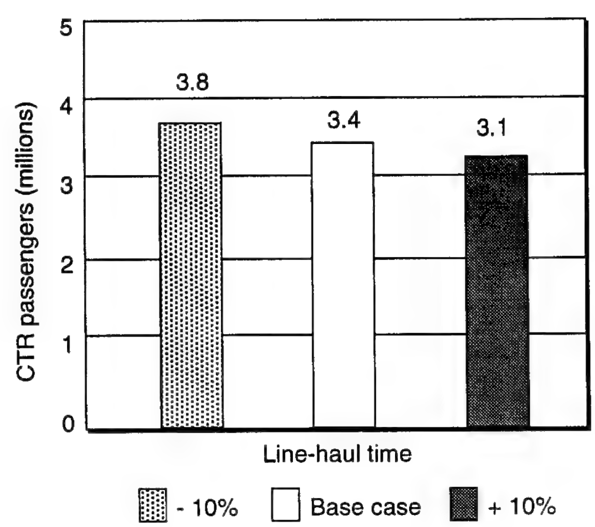


Figure E4.3.3-3 Variation in CTR Line-Haul Time - Northeast 2010

E4.3.4 Load Factor and Utilization Sensitivity

The base case assumption on CTR load factors is that a 60 percent average can be maintained for all CTR operations. The average load factor for all air carriers is currently approximately 66 percent. However, typical load factors for non-jet and/or short-haul operations are lower, typically below 60 percent. Load factors vary in different markets, and by season, time of day, and day of week.

The effects of variations in CTR load factor on average CTR costs and demand are shown in figure E4.3.4-1.

CTR Load Factor	Ticket Price	Passenger Demand
50 percent	$178	2.27 million
60 percent	$155	3.36 million
65 percent	$146	3.76 million

Figure E4.3.4-1 Effects of Variation in CTR Load Factor - Northeast 2010

CTR aircraft utilization is assumed to average 2,300 hours per vehicle per year. This is in the mid-range of results for regional jet and turboprop operators, with traditional Northeast shuttle carriers getting fewer flight hours per aircraft and Southwest Airlines getting more. Aircraft utilization is affected by operating conditions (e.g., climate and airport congestion), airline scheduling practices (e.g., allotted gate turnaround times), and time-of-day, day-of-week and seasonal peaking of passenger demand. It might be expected that CTR operations at smaller vertiports would result in lower average ground time than conventional air operations, and thus, relatively higher utilization. On the other hand, the primarily business market attracted to CTR would be expected to desire more peak-period flight times. This would result in lower utilization or lower average load factors if midday and weekend flights were scheduled.

The effects of variations in utilization rate on average CTR costs and demand are shown in figure E4.3.4-2.

CTR Utilization	Ticket Price	Passenger Demand
2,000 hours	$162	2.90 million
2,300 hours	$155	3.36 million
2,500 hours	$151	3.47 million

Figure E4.3.4-2 Effects of Variation in CTR Utilization Rate - Northeast 2010

The assumptions regarding CTR utilization and load factors might affect estimates of CTR economic performance in specific market areas. Each CTR is assumed in service for 2,300 hours per year regardless of market area differences in climatic conditions and airspace congestion. Also, a 60 percent CTR average load factor is assumed in all markets, whether the market traditionally has a high proportions of non-business travelers presumably spread more evenly during all hours of the day and week or a high proportion of business travelers whose travel peaks at certain times on certain days of the week. For many markets where bad weather, high airport congestion, and/or concentrations of business travelers would tend to lower attainable aircraft utilization or decrease average load factors below the assumed averages, estimated CTR costs and fares may be too low. The opposite might be true for less-congested, good-weather markets. The effects of using an single average CTR utilization rate and load factor for all markets is likely to result in marginally overestimating projected CTR economic performance in the Northeast and Midwest, and to underestimating CTR economic prospects in the Southwest.

Given the likely business travel orientation CTR passengers, it may not be possible to simultaneously achieve high load factors and high average aircraft utilization. Two simulations were run to show the impacts of combinations of assumptions about load factor and utilization. The case that combined 65 percent CTR load factor with 2,000 hours average utilization resulted in a 5 percent increase in CTR demand. Combining a 50 percent load factor with 2,500 hours utilization led to a 28 percent reduction in CTR demand. Changes in

assumptions about load factor seem to produce larger demand impacts than do changes in CTR utilization. This may be because variation in load factors can affect CTR demand through changes in required CTR fares and changes in CTR flight frequency. CTR utilization changes only affect CTR costs and fares.

E4.3.5 Vertiport Location Sensitivity

The number and location of vertiports are important determinants of potential CTR demand. The base case assumption is that vertiports could be located in optimal locations with respect to desired trip-end destinations without causing difficulties in land use and community acceptance. Also, it is assumed that the number of vertiports in a metropolitan area would provide sufficient capacity to serve all expected CTR passenger demands.

Two analyses were conducted to test the sensitivity of these assumptions. The first examined the impact of using inferior CTR vertiport locations, for example, in minor, non-central business district (CBD) urban activity centers, nearby suburbs, or airports. The other analysis examined the impact of restricting vertiports to only one location in each major urban area. In the Northeast, using all inferior vertiport locations resulted in a 31 percent reduction in CTR demand, while restricting the number of vertiports led to a 17 percent reduction in CTR passengers. In the West Coast corridor, similar alterations caused 33 and 25 percent reductions, respectively, in projected CTR demand. As noted above in the analysis of the effects of fare changes, the addition of a vertiport in New York increased passengers by approximately 21 percent above levels resulting from the fare change.

In the past several decades, only three new major airports have been built in the U.S. These are Dallas/Fort Worth, Denver, and Fort Meyers. All three are located many miles from the center of the cities that they serve. Of the few additional new major airports being considered, sites under discussion are also many miles from the center of the cities that they serve. Building vertiports in close proximity to centers of passenger demand will be a challenge in some major cities. However, for the foreseeable future, vertiports appear to be the only new aviation facilities likely to be built within 20 miles of the central business districts of any major cities.

E4.3.6 Vehicle Size Sensitivity

The base case assumed that a 40-passenger CTR would be used in all types of city-pair markets, specifically in large metropolitan area to metropolitan area markets as well as smaller feeder routes. This assumption was relaxed by testing the advisability of using a 19-passenger CTR design. Use of the smaller aircraft should allow more small feeder routes to become viable by increasing frequency. Conversely, demand in all potential markets might be reduced because the larger CTR is estimated to cost 32 percent less than the smaller CTR.

Results in the Northeast indicate that new feeder routes with CTR frequencies greater than 2 flights a day add approximately 275,000 passengers (6 percent) in 2010. However, use of the 19-passenger CTR on existing vertiport-to-vertiport and feeder routes would result in a loss of 1.9 million CTR passengers (42 percent). The smaller CTR seems to provide a small advantage in some markets, but its use would be inadvisable in many others.

Recent discussions with potential CTR manufacturers indicate that the development of several size CTRs is under consideration. These include a very small, nine-passenger version to replace helicopters used by offshore oil producers, corporate operators, police and emergency medical service (EMS) transporters. It is not likely that all of these different sized CTRs would be produced simultaneously, but a family of CTRs might be introduced over a 10 to 20 year period to fill various market niches.

E4.3.7 Cost Sensitivity

Several simulations were done to examine the impact of varying the overall cost of CTR operations. Figure E4.3.7-1 shows results of these sensitivity tests for costs ranging from 80 to 120 percent of the standard base case assumptions.

Corridor	Percent of Baseline CTR Costs		
	80	90	120
Northeast	+107	+53	- 45
Midwest	+159	+77	- 69
West Coast	+116	+50	--
Southwest	+97	+44	--

Note: 80% and 90% cases based on vertiport-to-vertiport CTR operations; 120% case includes feeder flights

Figure E4.3.7-1 Sensitivity of CTR Passenger Demand to Changes in CTR Costs - 2010 (Percent Change)

Figure E4.3.7-2 shows a summary of data generated in the analysis of CTR demand sensitivity to variation in key input assumptions. Note the importance of assumptions about conventional airfares, CTR costs, and vertiport locations.

Most sensitivity evaluations were conducted on the Northeast corridor for the year 2010.

Variable	Change in Assumptions	Change in CTR Ridership
Conventional airfares	+15%	+17%
	-15%	-17%
Conventional air delay per operation	+20%	+9%
CTR fares	-10%	+45% to +80%
	-20%	+95% to +160%
	+20%	-45% to -70%
CTR initial price	+10%	-10%
	-10%	+10%
CTR line-haul travel time	+10%	-7%
	-10%	+14%
CTR utilization	-10%	-11%
	+10%	+9%
CTR load factor	-10%	-19%
	+10%	+14%
Vertiport locations	Less favorable	-31% to -33%
	One per city	-17% to -25%
19-seat CTR	New routes	+6%
	Overall	-42%

Figure E4.3.7-2 Sensitivity of CTR Ridership to Variation in Key Assumptions

E5.0 Key Issues Affecting Market Acceptance of CTR

E5.1 Introduction

The development and introduction of civil tiltrotor (CTR) raises issues beyond those which attend the introduction of a new, conventional aircraft model. First, the introduction of CTR requires consideration of a new transportation system. CTRs will operate from dedicated vertiports as well as existing airports. In addition, there are concerns about how well CTRs will be accommodated by the air traffic control (ATC) system. Third, because CTRs will operate from vertiports located close to passenger demand centers, CTR noise emissions are an important consideration. Finally, the public acceptance of CTRs requires that these vehicles meet safety standards appropriate for commercial air transportation and are perceived by the public to be safe. This section discusses each of these key issues, and finds that:

- The ATC system can accommodate CTR aircraft in both the en route and terminal environments with only minimal impacts on other aircraft operations. As such, CTRs are likely to represent one means to increase the capacity of the national air transportation system.
- Vertiport siting is a key to the number of passengers that CTRs will attract. Vertiport costs are of a magnitude that they can be recovered from landing fees paid by CTR operators.
- CTR noise emissions will be an important factor in community acceptance of vertiports and CTR operations. Additional technology development is necessary to reduce V-22 noise to a level acceptable for CTR operations.
- Passengers and operators will have to be convinced that CTRs can be operated at a level of safety consistent with that for scheduled commercial air transportation. Because the V-22 has been developed for military missions, additional research is required to develop technology to enhance the safety level of tiltrotor aircraft operations.

E5.2 Air Traffic Control System Accommodation

The demands placed on the ATC system by CTR operations are important in determining whether such aircraft would off-load or increase air transportation congestion. If CTR operations can be conducted with only limited interaction with existing fixed-wing operations, the net potential to increase system capacity could be significant. Two analyses examined how CTRs could be accommodated within the ATC system. One of these examined the en route system while the other analyzed the impact of CTR on the terminal ATC environment.

E5.2.1 En Route System Accommodation

The Federal Aviation Administration (FAA) examined the effect of introducing CTR on en route airspace loads in the Northeast corridor (reference 14). The effects of CTR on en route system ATC loads were found to be minimal. Four demand scenarios were analyzed using the National Airspace System Performance Analysis Capability (NASPAC) Simulation Modelling System (SMS). These scenarios examined busy day traffic levels for both the year 1990 and the year 2000.

CTRs were assumed to replace fixed-wing aircraft on a seat-for-seat basis, and no additional fixed-wing operations were added above levels projected in the baseline scenario. The demand scenarios were developed from the Bell-Boeing Phase 2 Study of CTR conducted for FAA and the

National Aeronautics and Space Administration (NASA) (reference 15). The baseline scenario includes no CTR operations. This scenario is used to develop ATC loads without CTR traffic. The worst case scenario assumed that 100 percent of the CTR flights in the Phase 2 study were operated and that they replaced fixed-wing flights on a seat-for-seat basis.

The Northeast corridor was defined as a traffic network of seven corridor airports with collocated vertiports, 11 stand-alone vertiports, and 69 feeder airports. The activity between these facilities uses the airspace of seven air route traffic control centers (ARTCC). The analysis was restricted to 112 en route sectors that had more than two fixed-wing flights removed or CTR flights added. The objective of the analysis was to identify sectors with potential overload problems due to CTR and to estimate the magnitude of the problem. A number of metrics were used to assess the impact of CTR activity on the ATC system. These included:

- Average sector load during the peak quarter hour period.
- Minutes per day in which sector loads exceeds the 1991 sector capacity.
- The maximum instantaneous aircraft count in the sector.

The analysis found that only nine sectors appeared to have a potential overload problem under the highest level of demand examined. These instances involved only a small level of traffic and were only for a brief duration. One high-altitude sector at Washington Center appeared to have a capacity problem. However, this sector also was overloaded in the baseline case as well as the CTR replacement scenario. Thus, CTRs do not appear to have a significant effect on the duration or magnitude of the ATC en route system overload problem. Several other sectors may potentially have an overload problem. However, the simulations show that the magnitude of this problem appears to be very small. The study also recognized that the ultimate design and flight profile of CTRs, as well as any airspace redesign efforts undertaken prior to the introduction of CTR could have a significant effect on which sectors may face load problems, as well as the severity of any such problems.

During the next decade, significant improvements are planned for the en route ATC system, and these will increase airspace capacity and flexibility of the system. As such, it is expected that CTRs could be accommodated by the en route ATC system with only a very minor impact.

E5.2.2 Terminal Area Air Traffic Control

FAA also studied terminal area operations by CTRs to determine their effects on capacity (reference 16). The focus of the study was to examine CTR operations in the New York and Boston terminal areas to determine if these activities could be conducted without creating additional delay for conventional aircraft operations. CTR arrival and departure routes were designed for both terminal areas, and interactions between CTRs and conventional aircraft were simulated. The results indicate that up to 20 to 30 CTR operations per hour could be flown into each CTR landing area without increasing delays to conventional aircraft operations.

During this study, several assumptions were made regarding CTRs:

- CTRs will divert traffic from major metropolitan airports to a network of vertiports.
- Although future technology is expected to result in more flexible airspace routes, the flexibility of these routes will be limited in terminal areas due to the converging traffic flows experienced around airports.
- CTRs will be equipped with advanced navigation systems which will allow the use of the Global Positioning System (GPS) for en route navigation and precision approaches.

The analysis of terminal ATC considered seven vertiports in the New York area and three in the Boston area. This represents a larger number of vertiports and CTR operations than examined in the market study in Chapter E4 of this technical

supplement. Therefore, these results are conservative. Some key assumptions made during the analysis include:

- CTR operations will adapt to the existing airspace structure.
- Vertiport capacity will not limit the number of CTR operations.
- CTR operations will be exempt from conventional flow control and ground delay programs that are tied to runway acceptance[11].

This analysis indicated that airspace delays increased after a certain level of CTR activity was introduced. Depending on the individual locations and level of fixed-wing demand assumed, this number was between 20 and 30 CTR arrivals per hour at each CTR landing area. It is not likely that demand at these levels would occur at most vertiports. The projected demand at some of the larger vertiports can approach this level of activity, and may cause interaction with ATC services for other aircraft. Because CTRs were assumed to generally follow turboprop arrival and departure routes, most of the increased delays were for this type of aircraft.

The study concluded that it will be necessary to combine CTRs with conventional aircraft flows in congested terminal airspace. In addition, it noted that such activity will be feasible because CTRs will operate along with conventional turboprops on arrival and departure routes. However, after the initial arrival phase, CTRs will be vectored off turboprop routes onto exclusive GPS routes that lead to and from vertiports.

Both analyses indicate that CTR activities are not likely to increase delays materially for other aircraft operations over sustained periods of time. As such, CTRs are likely to provide a net increase in capacity if they can be adapted to the national air transportation system. In fact, as noted in Chapter E8 of this technical supplement, the introduction of CTRs has the potential to provide substantial delay reduction benefits.

E5.3 Vertiport Issues and Cost

The demand center to demand center mission requires that vertiports be sited close to passenger origin and destination points. Vertiports also will have to be located where there is a compatible land use, or be large enough to enclose noise levels which are objectionable to neighbors[12]. This threshold noise level depends, in part, on land uses surrounding the vertiport. For operation at airports, it is likely that CTR noise emissions could be contained within the airport boundary. CTRs also will have to operate on arrival and departure flight paths and profiles which minimize noise impacts on the community.

Vertiport ground access times that are shorter than current airport access times are critical to the commercial success of CTR. Achieving this access time may require the presence of multiple vertiports within some cities, helping to make CTR a highly competitive mode of intercity transportation.

Vertiport capital costs for all structures and equipment are projected to vary from under $10 million for small facilities located at existing airports to about $125 million for larger capacity vertiports built on new piers in metropolitan area harbors. This does not include ATC costs. The analysis also projects that vertiport CTR landing fee revenues and concession income is likely to be sufficient to defray the operating and annualized capital costs of the network of vertiports needed in the Northeast and possibly other regions of the country. This assumes that vertiports share in Airport Improvement Program (AIP) funds generated from CTR passenger ticket taxes.

[11] Specific CTR routes were modelled using the graphical airspace design environment (GRADE) computer graphics model. The model was used to display aircraft flight tracks, instrument approaches, and the overall traffic patterns of the Northeast Corridor airports. It also allowed the development of CTR routes used in the analysis. Interactions between CTRs and conventional aircraft in the New York Terminal Radar Approach Control (TRACON) area were simulated using SIMMOD to estimate the impacts of increasing numbers of CTR operations on delays in the New York area.

[12] This report presents CTR noise emissions in terms of day-night noise levels (LDN), the accepted metric for aircraft noise. The character of CTR noise emissions, however, are unlike those of conventional aircraft. Some argue that a new noise metric will have to be developed.

E5.3.1 Costs Vary by Vertiport Type and Location

Vertiport costs were derived from elemental design criteria for a set of generalized vertiport layouts which might be located in city centers and suburban locations. The types of vertiports for which different design specifications and cost estimates were derived include: city-center on piers and elevated; suburban elevated and on ground; and at airports. For each vertiport type, different cost estimates were developed depending on the number of CTR operations expected at each facility. Larger numbers of projected CTR operations translates into the need for increased number of CTR touch-down and lift-off (TLOF) surfaces. Larger volumes of CTR passengers results in the need for additional gates and terminal areas. It is estimated that approximately 1.1 million CTR passengers could be handled annually for each CTR TLOF area provided.

CTR vertiport costs were estimated taking into account unit costs and quantities of the following airside and landside components:

- TLOFs with a 400-foot rollway
- Final approach and take-off areas (FATO) which surround TLOFs
- Taxiways between TLOFs and from TLOFs to gates
- Aprons and jetways
- Lighting and marking equipment
- Fueling, snow removal, fire fighting, and rescue (ARFF) equipment and facilities
- Land, fencing, and site work
- Piers
- Terminals
- Auto parking facilities.

Vertiport construction and land acquisition costs were adjusted for regional differences according to the Means construction cost index. The cost index varies from 0.84 to 1.33.

The estimated vertiport costs by type and CTR capacity are presented in figure E5.3.1-1.

Location	Type	Cost Range (in millions of dollars)
City center	Elevated vertiport	10 to 40
	Vertiport on new pier	90 to 125
Suburban	Ground vertiport	6 to 20
	Elevated vertiport	10 to 25
Airport	Existing facility	0 to 10
	New airside facility	2 to 17

Note: Upper end of cost ranges does not include full cost of noise or environmental mitigation

Figure E5.3.1-1 CTR Generic Vertiport Cost Range

Much of the difference between city and suburban vertiport costs results from assumptions regarding automobile access and parking requirements. City vertiports are projected to require fewer parking spaces because a higher percentage of CTR users are assumed to access vertiports via public transportation, taxi, and drop-off. On the other hand, city vertiports and suburban elevated vertiports are assumed to require auto parking structures which are much more expensive than the marked black top used at suburban-ground vertiports (i.e., $10,000 versus $1,500 per space).

Vertiport land requirements vary with the type of structure (i.e., elevated or ground-level) and its passenger handling capacity. The amount of land area reserved for gates assumes the use of jetways. These protect arriving and departing passengers from CTR prop down-wash and allow simultaneous operation at closely spaced gate locations. Without jetways, additional gates and/or greater separation between gate areas would be needed.

E5.3.2 Land Requirements and Costs

In addition to structures and reserved airspace, vertiports impact surrounding land areas because of CTR noise. Although not counted in estimates of vertiport costs, noise mitigation and/or purchases of surrounding land may be significant expenses (see Infrastructure Subcommittee report). The estimated vertiport land requirements for various types of vertiports, with and without noise impacted areas, are shown in figure E5.3.2-1.

	Land area (in acres)
Required for operation	10 to 30
Noise-impacted area	10 to 119

Note: Noise requirements were calculated at DNL 65 and vary with number of operations. Required land area for operation may be less than 20 acres if vertiport is located on waterfront site or a multilevel structure, such as parking garage. Residential sites could require approximately 119 acres.
Source: CTRDAC Infrastructure Subcommittee

Figure E5.3.2-1 Vertiport Land Facility Size Requirements

Through landing fees and AIP grants, the system of Northeast vertiports can be expected to more than cover all operating and annualized capital costs in 2010. This assumes that net vertiport operating expenses will be approximately $2.10 per enplanement, a figure derived by averaging the costs at several smaller airports. This also assumes that the distribution of airline ticket taxes to cover vertiport operating and capital expenses will be at a level equal the national average (i.e., 37.4 percent). In addition, all ATC capital and operating expenses are assumed to be covered by the remainder of ticket tax receipts.

If these assumptions are correct, it is unlikely that significant vertiport operating subsidies will be required in any corridor.

E5.4 Noise Reduction Technology

Noise emissions have an effect on CTR economic viability. A recent NASA study concluded that community acceptance of external noise level of CTR is mandatory for CTR system success. If vertiports are not close enough to demand centers, the CTR may not gain sufficient traffic levels to achieve commercial success. Sensitivity analyses in Section E4 of this technical supplement show the relationship between vertiport location and market penetration. From a technical point of view, reducing noise is one of the most important, yet most difficult, challenges in developing a commercially successful CTR. Because it is an important key to system economic viability, noise reduction tops the list of needed research.

The need to reduce external noise levels of the CTR to predicted levels will require research into new rotor systems and a demonstration that CTR can achieve lower noise levels. Several approaches, including increasing the number of blades, have the potential to provide the needed noise reduction. The economic analysis assumes that CTR technology has benefited from such noise reduction research by the time CTR is introduced into service. If this is not accomplished, it would reduce community acceptance and, consequently, the projected demand for CTR vehicles.

E5.5 Vehicle Safety and Reliability Issues

Aircraft safety is a key public concern. CTRs will have to be designed for a level of safety equivalent to other commercial transport aircraft in order to realize projected levels of demand. As an entirely new type of aircraft, CTR in particular needs to assure airlines and passengers that it provides the safety level expected of scheduled passenger operations. To meet this development challenge, additional research is needed to ensure that CTR is designed to meet such safety standards. Comparing CTR to a helicopter is misleading because it might suggest a lower level of safety than fixed-wing aircraft. CTR will not only be designed to airline standards, but it will be flown in controlled airspace, which is not the case with non-airline helicopter operations.

As noted in Chapter E7 of this technical supplement, the results of focus group sessions conducted as part of the Civil Tiltrotor Development Advisory Committee (CTRDAC) effort indicate CTR safety will have to be proven to gain passenger acceptance. Safe operation will have to be demonstrated over a period of time before a large number of passengers would choose CTR over conventional aircraft. Operation of the V-22 will provide some service experience. If manufacturers decide to launch a small CTR before the introduction of a 40-passenger vehicle, this would be another source

of service experience. In focus group interviews, Government certification was not viewed as sufficient to allay the safety concerns of some passengers. Research which improves the reliability and safety of CTRs is necessary.

Dispatch reliability is a key operator concern. Only the highest level of reliability, especially dispatch reliability, is acceptable in airline operation. To achieve this goal, additional research is needed to reduce the complexity of CTR aircraft and minimize maintenance requirements.

E6.0 Manufacturing Economics

E6.1 Manufacturer's Perspective

A manufacturer will only launch a civil tiltrotor (CTR) program when it believes it can sell enough units over a short enough period of time at a price sufficient to recover investment and manufacturing costs while earning a return on the capital employed. A manufacturer also will need firm orders from customer airlines to launch a CTR program. In addition to resolution of infrastructure issues and obtaining airline operator interest in CTRs, the key quantitative factors affecting a CTR launch decision include:

- Development and tooling costs
- Rate of learning on production costs
- Number of units sold
- Time over which units are sold
- Prices realized (based on value to airline)
- Cost of money (reflecting risk and cost of capital)

Typically, transport aircraft manufacturers require from 400 to 800 unit sales for a program to break even.

The cost to build CTRs can be estimated within reasonable bounds based on prior experience and in a generally accepted industry-wide format. The estimation process requires dividing costs into two major categories, nonrecurring and recurring. Nonrecurring costs are associated with designing the vehicle and preparing for production, including design and construction of tooling and facilities, production of test articles, and general testing and certification. Recurring costs are those that occur with each vehicle produced, including engines, airframes, rotors and drive systems, interiors, and avionics. Recurring costs are influenced by production rate and the learning curve effect. Higher production rates allow more favorable terms on purchased items and allow the allocation of fixed development and tooling costs over more units. The learning curve refers to the phenomenon whereby the production workers and production processes *learn* to be more efficient in producing subsequent CTRs, lowering the cost of subsequent units produced.

Of these two influences, the learning curve is most pronounced. Historically, successful commercial airliner programs have experienced learning curves in the 80 percent to 90 percent range. This means that for an 85 percent learning curve, the unit cost is reduced by a factor of 0.85 every time the quantity produced doubles. On very large production runs, the later phases normally experience a lesser rate of learning. Conversely, lower than expected production rates also can reduce the learning curve benefits as personnel turnover and less efficient tool use occurs.

E6.1.1 Key Factors Affecting Launch Decision

A CTR launch decision is not purely a technical or economic one. Actions or non-actions by potential operators and the Government will be principal considerations of a manufacturer on when and if a launch decision is made for a CTR program. An overview of how manufacturers view those external risks together with prospects for resolving or reducing those risks is discussed in Chapter E10 of this technical supplement. The remainder of this chapter focuses on those economic factors considered by a manufacturer in its decision to launch a CTR program.

E6.1.2 The Cost-Price-Market Loop

The most significant economic factor in the CTR launch decision is the assurance of profitable production of aircraft. Clearly, a satisfactory business case requires that the average cost-to-build for the quantity sold be less than the market-driven selling price. In other words, a cost-price-market loop needs to be closed. Commercial aircraft today are "market-base" priced. Their selling price is based solely on their value to the user. "Value" is established by how well the aircraft meets the operational requirements of the buyer, compared to competitive options available, and profits likely to be earned from its operation. Selling prices result from buyer/seller negotiations. Commercial aircraft prices publicly quoted are invariably analogous to new automobile sticker prices. It is not possible to generalize actual selling prices since they vary depending on the competitive scenario (reference 17).

In the case of manufacturing conventional transport airplanes, this is a well known process. Cost-to-build estimates, even in the very preliminary stages, are based upon a well calibrated costing methodology. Development time, manufacturing processes, labor and materials can be determined within fairly narrow limits. Production tooling is usually an extension of experience from other programs. Proven production techniques and organization are applied to the aircraft. It is business-as-usual. On the market side, there is a wealth of evidence relating to what market value the customer will attach to the proposed product, and hence what the operator will be willing to pay for it. The new aircraft will operate in a predictable way using well established infrastructure. It is business-as-usual.

For a CTR, none of these conditions exist. It is not a market opportunity based upon a prior business model. There is no commercial cost base. There is no market experience, no operating data, and no true gauge of market value. Only 10 experimental tiltrotor aircraft have ever been built and those comprise three different models, in three different decades. Therefore, in evaluating CTR economics, business-as-usual solutions are not likely to yield more than rough approximations of cost and market price.

Two factors will drive the cost estimates for CTR. The first is the very different nature of commercial design versus military experience. For that reason, extrapolation of V-22 data is not a valid starting point. Zero-base estimation is necessary for the commercial design. The second is the necessity to diverge from the business-as-usual techniques based on past industry practices. There are revolutionary changes going on in the aircraft manufacturing business, some of which have produced new levels of efficiency similar to other types of businesses. These include computer-based design, new materials and processes, reduced cycle times, and integrated design-manufacturing teams. These changes have been observed in new V-22 parts being fabricated today.

E6.1.3 Market Price

As on the cost-to-build side, there is no prior business model for the market price side. There is no relevant experience. The question, "What is the market value of a CTR?," has not been answered with any degree of certainty. Some previous studies, notably National Aeronautics and Space Administration (NASA)/Federal Aviation Administration (FAA) Phase II (reference 18), suggests a market-driven price between $12.4 and $15 million dollars, or $14.2 to $17.2 million 1993 dollars. This price range was approximately 1.5 times the per-seat average price of turboprop aircraft then selling at $210,000 to $250,000 per seat. For the Civil Tiltrotor Development Advisory Committee (CTRDAC) study, a market price of $17 to $20 million has been assumed for use in the market demand analysis. Price, however, may not be the only measure of CTR market viability. Much more needs to be done to develop a better understanding of the CTR and its use in commercial air transportation in order to assess its true market value.

Closing the cost-price-market loop, where neither factor is known with great certainty, is essential to a program launch decision. Management,

engineering, and manufacturing have to make the necessary trades to minimize the cost-to-build number. Market price and cost-to-build must cross at a point which yields the desired financial returns to the manufacturer as well as providing for profitable operations for CTR operators.

E6.1.4 An Acceptable Business Case

The financial risks for private sector commercial aerospace programs are large. The commitment to build a new commercial passenger aircraft can entail several billion dollars in up-front investment for development, tooling, facilities, certification and initial production inventory. Projects take a long time and the manufacturer must endure large negative cash flows in the early years. The boundary conditions for a CTR launch decision include:

- A market which would absorb not less than 500 aircraft as determined by the manufacturer assessment, at a sufficiently high delivery rate to minimize the financial recovery period. This affects the cost of financing the early year negative cash flows.

- Specific launch customers identified for a significant portion of the 500 aircraft with orders or options in hand.

- Commitments to develop vertiports with funding assured.

- Data from V-22 operational experience on performance, maintainability, reliability, and safety flight available as needed to gain customers. This is contingent on the success of the basic V-22 program, which is itself essential to a CTR launch decision.

- Technical risks resolved to acceptable levels, especially noise reduction and safety.

E6.2 Worldwide CTR Market Demand

Several sources were used in developing the worldwide CTR market demand projections for this study. The primary quantitative analysis was the detailed market demand analysis prepared for the FAA by the Volpe National Transportation Systems Center. As noted in Chapter E4 of this technical supplement, this provided an up-to-date assessment of the likely CTR market in four high-density travel corridors in the U.S. These estimates were used in combination with prior studies, such as the two phases of the NASA/FAA civil tiltrotor studies which considered worldwide market demand. Phase I of that study identified several market segments, the largest of which was for a 36- to 45-passenger aircraft for use in regional air transportation. Phase II of the NASA/FAA effort, focused on the economic performance of, and potential world market demand for, a 40-passenger tiltrotor.

As noted in Chapter E4 of this technical supplement, the Volpe Center analysis covered four primary U.S. corridors and three categories of potential air travel diversion (vertiport-to-vertiport, feeder, and transfer). For purposes of developing a worldwide estimate of CTR requirements, the vertiport-to-vertiport and feeder market results were added together to establish a "lower bound" forecast for the four U.S. corridors. Adding the transfer requirements, which represent a more speculative opportunity for CTR diversion, creates an "upper bound" level. Using the relation between the Volpe Center four corridor values and the earlier NASA/FAA II estimates for the same corridors, values for the North American regions not modeled by the Volpe Center (e.g., Hawaii, Gulf Coast, Southeast and Florida, and Canada) were scaled to the Volpe Center market projections.

To estimate CTR demand potential in foreign countries, the committee relied on industry marketing studies performed after the NASA/FAA Phase II study. Because of significantly different economic and social climates in these countries, as well as variations in analysis methods and assumptions employed, there is substantial uncertainty about the levels of projected CTR demand outside the U.S. In 1992, a detailed analysis of the European market for a 40-passenger tiltrotor was completed by U.S. and European industry (reference 19). Eurostudy evaluated the competition from the European emerging high-speed rail system and determined the CTR market capture. Eurostudy projected a year 2010 demand of 129 to 1,226 CTRs dependent on fare levels. A demand for 300

units was identified as the baseline case. A major Japanese market study is now being conducted by industry, but results will not be complete until later this year. Preliminary information indicates a market of 300 to 400 aircraft. The NASA/FAA Phase II estimate for Oceania was reduced by the ratio found in the U.S. corridors. Other regions, including South America, Africa, much of Southeast Asia, and the Middle East, have not been included in the market demand projections. To the extent that these regions have CTR requirements, they would be in addition to those identified below.

The market projections also include 75 to 150 aircraft for other missions such as package express. These were identified in discussions with that rapidly growing industry during the NASA Phase I study. Figure E6.2-1 shows the worldwide CTR market projection for a 40-passenger aircraft. The projections range from 1,160 to 1,600 aircraft in the year 2010 depending on the level of transfer market penetration. These projections exceed the minimum of 500 to 700 units required by manufacturers to earn a commercial rate of return. Minimum manufacturer CTR production levels are discussed later in this chapter.

Market Region	Forecast Range
Four major U.S. corridor markets (note 1)	235 to 325
Other North American corridor markets (note 1)	150 to 200
Europe	300 to 400
Japan	300 to 400
Oceania	100 to 125
Total passenger CTRs	1,085 to 1,450
Other applications (note 2)	75 to 150
Total	**1,160 to 1,600**

Note 1: Vertiport-to-vertiport, plus feeder, plus transfer markets. Transfer market included in top end of the range

Note 2: Other worldwide applications for 40-seat aircraft include package express, corporate, search and rescue.

Figure E6.2-1 Worldwide Demand Forecast for 40-Seat CTR in 2010

E6.3 International Competition

While most analyses to date assume that the U.S. manufacturing industry would launch a CTR program, other countries have a keen interest in this technology. This section discusses the competitive issues regarding CTR manufacturing.

E6.3.1 United States Lead

From a technical and manufacturing perspective, developing and producing a CTR aircraft is well within the capability of U.S. industry. Since the 1950s, three generations of tiltrotor aircraft have been built and flown. The latest, most complete effort is the 45,000-pound V-22 Osprey under development for the Department of Defense. Now in the Engineering and Manufacturing Development (EMD) phase, the V-22 is slated for production by the end of this century and well into the next.

Two companies are teamed on an equal basis for the V-22 program. These are the only two companies in the U.S. now having the technology to design and build tiltrotor aircraft. However, a broad-based U.S. industrial team is involved in many aspects of this project. The V-22 forms the technology base for a CTR.

These manufacturers together have invested over $600 million in tiltrotor programs. They have stated an intent to work together on any size/class CTR project. At such time as tiltrotor aircraft markets develop in one or more sizes, other companies may share in such programs. Some aerospace companies may elect to evolve their own technology base as independent producers. However, to provide a perspective on the size of the helicopter industry from which tiltrotor technology has emerged, 1994 sales for the whole helicopter industry totaled a reported $5.3 billion. This represents approximately 3 percent of the output of the U.S. aerospace industry. The U.S. helicopter manufacturing industry has the capability to develop a CTR and can be expected to do so when conditions external to the manufacturer mature.

E6.3.2 Europe

In 1987, the European Council of Ministers chose the European Future Advanced Rotorcraft (EUROFAR) as a multi-nation effort to develop a tiltrotor aircraft under EUREKA, a joint initiative on a wide range of civil research and development (R&D) projects. France, Germany and Italy (29 percent each) joined the United Kingdom and Spain (6.5 percent each) in a $38.4 million feasibility study. These studies through 1992 resulted in a plan for a $225 million development prototype aircraft to be flown in 1997. The recommendation was not approved. France (Aerospatiale) continued on the project and has built and wind-tunnel tested a scale proprotor of an advanced design.

By April 1993, a new Phase II team (67 percent Eurocopter (France-Germany)) and 23 percent Westland (United Kingdom)) entered a continuing definition phase for a 30-passenger commercial tiltrotor. This $10.8 million follow-on project was announced in 1993 as the first step toward the first flight of a demonstrator by the end of the decade. Further goals are for a 2004 production go-ahead with first flight in 2006 and certification in 2009.

Clearly this European team is technically competent to build and fly a tiltrotor aircraft. Funding is a question of government commitment which in turn is a question of political timing. At present, tiltrotor is too small an issue to be on the political agenda. If the European governments decide to subsidize it, a EUROFAR tiltrotor could emerge as a full-fledged world competitor as did Airbus in transport category airplanes. Some Europe watchers predict the project will await U.S. development of aircraft and infrastructure. Development of a U.S. CTR would make it easier for them to fight the very difficult European environmental battles on infrastructure which would likely ensue over vertiport siting.

The U.S. may have a 7- to 10-year lead over the Europeans for development of a CTR, but if government funding is made available to European manufacturers, much of this advantage could be eroded quickly.

E6.3.4 Japan

Japanese aviation industries have been watching tiltrotor development with a great deal of interest. While their aviation industry is only about 5 percent of the size of the U.S. industry, it has demonstrated a high degree of technical and manufacturing skill in a wide variety of aircraft programs. Japanese aircraft manufacturers are very attuned to home market needs, especially short-haul air transportation. A major study on the potential demand for a CTR is underway. This effort, underwritten by the manufacturers, was scheduled for completion in the middle of 1995. It can be expected to show significant potential demand but also to highlight that infrastructure issues in Japan are far more contentious than in the U.S.

The Japanese aviation industry is very capable, with superb quality demonstrated in aircraft production. The Ministry of International Trade & Industry (MITI) provides a majority of start-up capital for favored projects, often through loans which are repaid as a function of the degree of project success. Japanese aerospace manufacturers are very good in developing and applying technologies such as composite materials, both in joint design projects and in co-production. While it is unlikely that the Japanese aviation industry would develop a tiltrotor aircraft independently, they would make excellent partners for projects which were pointed at producing CTRs for the Japanese market or other countries in the region.

E6.3.5 Russia

The basic problem facing the Russian aircraft manufacturing industry is a lack of money. Although their aviation industry is highly skilled in many areas, they do not have the technology to build a tiltrotor. It is believed that they have done tiltrotor pre-design work and wind tunnel testing in the past. Russian commercial aviation products, burdened with defense orientation and the expectation of operations in unprepared areas, are rugged, heavy and inefficient, but they are very inexpensive on the world market. Their design solutions lack "elegance" as they cannot afford what is

considered basic in the U.S. (i.e. computer design and drafting, computer analysis of composite structures, fly-by-wire flight controls, etc.). On the other hand, many Western aviation products might not survive the extremely harsh conditions of Siberian operations for which many of their rugged products are designed. The Russian aviation industry is financially constrained. Projects with world visibility, such as space exploration, consume all available government funds for aerospace. The industry is undergoing a transition as Russia shifts to a market economy. A Russian tiltrotor would not be expected to appear until well into the next century, and then perhaps as a joint development with another country.

E6.3.6 Potential Partner Arrangements

The size of the tiltrotor market will limit the number of companies that elect to become involved. Due to large investments in time and the large negative cash flows in the early years of a program, it is safe to assume that only major companies would launch a CTR program and then only with well defined potential markets. For the U.S. market, the two existing tiltrotor manufacturers intend to remain teamed. Other aircraft industry suppliers are likely partners.

If the CTR market gains strength beyond current expectations, more than one source may emerge, especially a foreign manufacturer as suggested above. Considering that possibility, a number of scenarios can be postulated. There is a trend in the U.S. commercial aerospace sector to establish relationships with non-U.S. companies in order to develop and build new-generation commercial jets. Typically this involves the participating companies providing investment funding to develop tooling to support their production activities. They expect to recover their investment from the sales of components they manufacture. This type of relationship provides a reduced exposure to the lead company and demonstrates a commitment to the project by all team members. There are clear motives for collaboration which can be identified from the substantial experience which now exists. The major ones are to:

- Improve market access in partner countries.
- Reduce financial risk for each partner.
- Reduce competition.
- Improve long-term business stability.
- Enable technology transfer.
- Increase product base.
- Expand market prospects.

The type of relationship depends upon the balance of these motives as seen by each participating company.

Many parts and components of the CTR will have much in common with well established foreign aircraft manufacturing technology and methods. Items such as the use of composite materials, digital cockpits, and fly-by-wire controls are common to many companies abroad. It is only CTR design technologies that are unique.

To consider a number of possible competitive manufacturing scenarios, a matrix for market division in future international markets can be developed (figure E6.3.6-1). This varies from Box 1, where there is no foreign source, to the other extreme in Box 4 which assumes a foreign source has evolved prior to, or in lieu of, a U.S. source. This latter case is one of delayed market entry, or a failure to exploit this market by U.S. industry. This would be a monopoly market for a non-U.S.

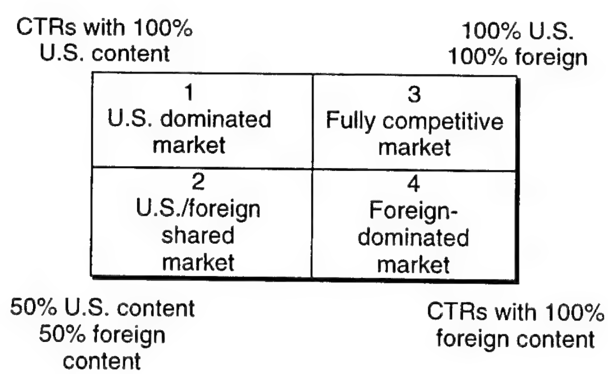


Figure E6.3.6-1 Market Division Matrix

source, probably made possible by government subsidies in the start-up and production phases of a CTR program.

In between, there are cases 2 and 3. If, for a number of market reasons, foreign industry involvement is sought, the most likely situation is Box 2, where foreign aviation companies enter as subcontractors or suppliers on a U.S. CTR program. This can be very valuable as these partners often contribute design and tooling investment and bring market share. It would also avoid a situation where two manufacturers enter the market in competition with one another and neither program makes money. In later years, if a sufficient market exists to support a second manufacturer, a second CTR program could emerge. In that case, Box 3, there would be a fully competitive situation in some markets, especially home markets, and less competition in others.

A more likely possibility is that a second, foreign, source might elect to avoid direct competition by building a different size CTR aircraft than is available on the U.S. market. This would avoid price competition and the resulting reduction in producer profits. An alternate size vehicle would create a greater overall market for CTR aircraft and could actually increase the market for both sizes of aircraft as the technology matures and more infrastructure is developed.

Positive steps by the U.S. Government in supporting the research base for CTR through NASA could assure that U.S. industry exploits its lead in this technology. In the event Government support is not provided, U.S. industry may forego this market. Foreign government financial support for its manufacturers to take advantage of the market for CTR aircraft could lead to the loss of a major industrial and technological opportunity for the U.S.

E6.4 Development Timing Issues

The timing of development for a CTR program launch depends on a number of factors. As discussed in Chapter E10 of this technical supplement, some of these, such as the development of vertiports, are beyond the control of the manufacturers. In addition, there is additional research required. The timing and results of this research, as well as how it is financed, also affect the likely commercial viability of a CTR production program and the decision of a manufacturer if and when to launch a program. In addition, one U.S. manufacturer believes that a smaller commercial tiltrotor (on the order of nine seats) aimed at the utility market (i.e., industrial, air taxi, corporate and other uses) could be launched prior to the development of a 40-passenger vehicle for scheduled passenger transportation. As such, there is considerable uncertainty about the actual timing of CTR development. The discussion below considers the earliest time frame in which a U.S. manufacturer could launch a CTR program.

Given time for additional research and assuming a 5-year development period after program launch, it is assumed that the earliest delivery of a 40-passenger CTR would occur in the year 2004 or later. In the discounted cash flow analysis below and in the assessment of private and social benefits presented in Chapter E9 of this technical supplement, it is assumed that first deliveries take place in 2004. Using the production rate assumptions presented below, it is assumed that sufficient vehicles are delivered to the U.S. market to meet the projected demand in the vertiport-to-vertiport and feeder markets by the year 2010 for the four U.S. corridors. Additional production is assumed to be exported and sold overseas. In a sensitivity case, the analysis assumes that vehicles for the CTR transfer passenger market in the four U.S. corridors are also delivered.

E6.5 CTR Manufacturer Cash Flow Analysis

A discounted cash flow analysis model was developed to determine the number of CTRs required to produce a positive net present value (NPV) for the production program, given certain assumptions. These assumptions include a selling price of $18.5 million per CTR in 1994 dollars, a full production rate of seven CTRs per month, a real discount rate of 12 percent, and a two-stage

learning curve of 85/90 percent before and after full production rate begins. The analysis shows that 506 units would have to be sold within 10 years (41 quarters) from go-ahead for the program to have a positive NPV. This number is well below the worldwide market projection. If production exceeds 506 units over the time period shown, the program return will be larger than 12 percent in real terms. The cash flow analysis is based on a nonrecurring development cost of $1.2 billion. This assumes that a Government-funded research program precedes program launch. The sensitivity of this assumption is tested below.

The results shown in figure E6.5-1 reflect net after-tax expenditures and account for the time value of money. Although the total manufacturer research and development cost outlay is $1.2 billion in nominal terms, it is assumed that these costs are expensed in the year incurred for tax purposes, lowering the net outlay. Moreover, the research and development costs (nonrecurring) are not incurred all at once, but over a span of 5 years. For this reason, the present value of these expenditures is less than the nominal outlay.

The cash flow analysis model assumes the time value of money is treated in a consistent way by finding the set of production costs over time that will yield a desired rate of return. This eliminates any dependence on an "average cost" at some level of production (e.g. 500 units). The analysis uses a

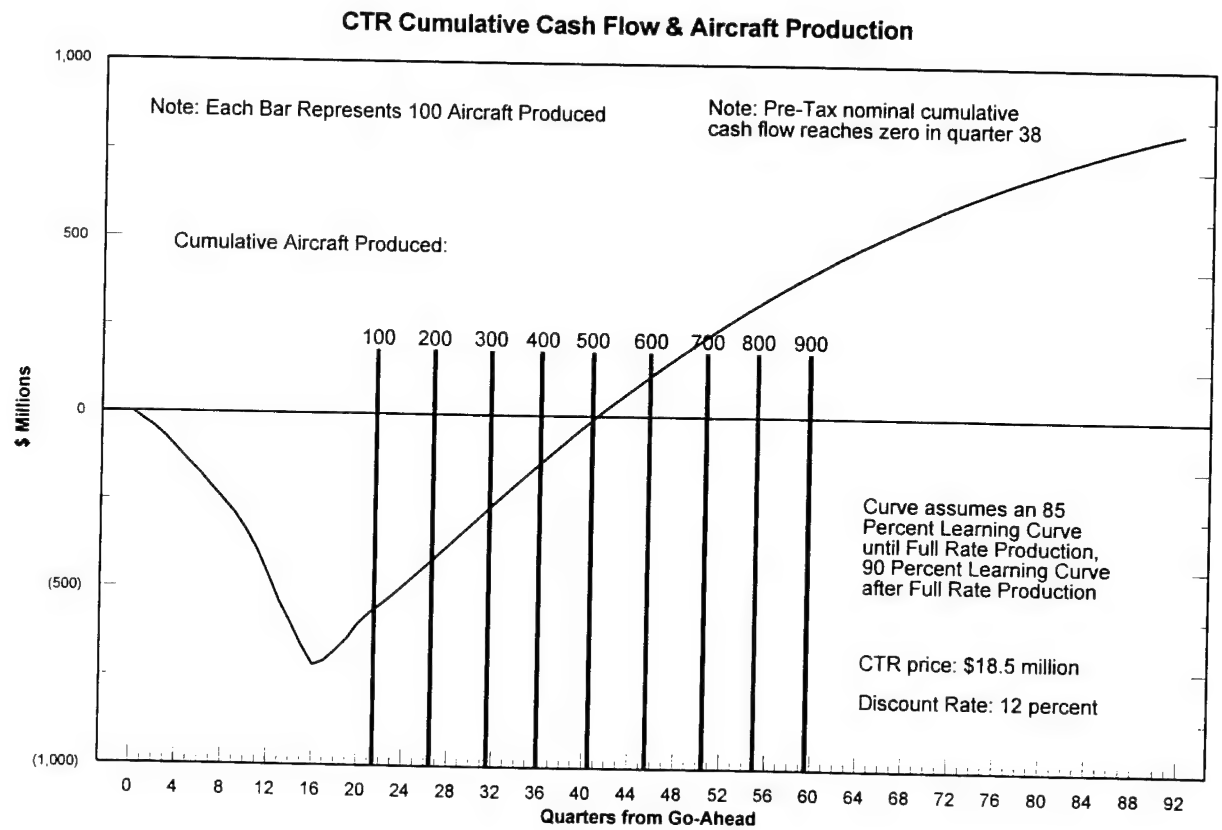


Figure E6.5-1 CTR Cumulative Cash Flow and Aircraft Production

two-stage learning curve in order to draw a distinction between aircraft production and delivery schedules before and after full rate production begins. This reflects the fact that early aircraft are used as test aircraft. These aircraft are eventually sold, usually after some refurbishment. Refurbishment costs, however, are not considered in this analysis. The effect of this exclusion is judged to be insignificant relative to other uncertainties.

Other model assumptions include:

- Additional research will be performed by various parties as planned, reducing costs for the development phase.
- Engine costs and Master Changes/Buyer Furnished Equipment (MC/BFE) costs are treated as straight pass-throughs with no return to the CTR manufacturer.
- Initial spare parts sales which accompany each aircraft sale are included as a constant revenue stream of 2.5 percent of gross sales (excluding engine and MC/BFE) with a profit margin of 15 percent.
- Additional spare parts sales are included as a constant revenue stream at 0.5 percent of cumulative gross sales with a 2-year lag (excluding engine and MC/BFE) and a profit margin of 15 percent.

Sensitivity analyses (figure E6.5-2) were performed on manufacturer returns by varying aircraft selling price, nonrecurring costs, and with and without Government research funding.

Non-Recurring Costs	Aircraft Selling Price	Manufacturer without Gov't R&D (note 1)		Manufacturer with Gov't R&D (note 2)		Break-even Year	Break-even Aircraft
		NPV at 12% in 2010	IRR	NPV at 12% in 2010	IRR		
$1.2 billion	$18.5 million	$(89)	11%	$273	23%	2013	506
	$17 million	$(223)	8%	$128	17%	2016	758
$1.8 billion	$18.5 million	$(205)	9%	$157	17%	2016	779

Note 1 - Assumes manufacturers pay 100 percent of research and development program
Note 2 - Assumes Government pays pays 100 percent of research and development program

Figure E6.5-2 Sensitivity Summary

E7.0 Customer Economics

E7.1 Operator Cash Flow

A discounted cash flow analysis of civil tiltrotor (CTR) operations was performed based on the fares, costs, and number of passengers identified above. It covers CTR operations in the four U.S. corridors starting in 2007 and running for 20 years. Figure E7.1-1 summarizes cash revenues and expenditures in 1994 dollars for CTR operations in the four U.S. corridors. These include all investment and operating costs as well as taxes. In addition, the cash flow in figure E7.1-1 also reflects a terminal value because it is assumed that operations end in 2027 with the disposal of the CTRs. Figure E7.1-2 shows the annual cash flows for each year in this period across the four U.S. market areas. Early year negative cash flows must be financed, but these are more than offset by positive cash flows in later years.

Under these assumptions, the operator after-tax internal rate of return (IRR) and net present value (NPV) at 10 percent for each corridor are shown in figure E7.1-3. Across all corridors, the overall rate of return is approximately 11 percent.

An analysis was performed to measure the sensitivity of operator cash flow forecasts on rate of return to variations in key assumptions. A summary of the results is shown in figure E7.1-4.

Corridor	Revenues	Ownership Costs	Fixed Operating Costs	Variable Operating Costs	Taxes	Net Cash Flow
Northeast	19,200	(7,200)	(500)	(9,600)	(650)	1,250
Midwest	11,000	(4,000)	(160)	(5,800)	(350)	690
Southwest	750	(300)	(30)	(340)	(30)	50
West Coast	4,900	(1,900)	(240)	(2,360)	(150)	250

ASSUMPTIONS/METHODOLOGY:

- Between initial year of operation and 2010, operating revenues are assumed to be proportional to revenue passenger miles (RPM) which are based on assumed ramp-up estimates.
- Salvage revenue is earned when CTRs are sold after assumed 15-year operating life.
- Costs were broken into three categories:
  (1) aircraft ownership cost—assumes purchases are financed with 85 percent loan over 15 years at 7 percent interest.
  (2) fixed costs (5 percent)—incurred during any year when operations occur.
  (3) variable costs (95 percent)—assumed to be proportional to RPMs (unit RPM cost calculated using Volpe estimates for 2010).
- Following IRS rules, aircraft are depreciated over 7 years for tax purposes.

Figure E7.1-1 CTR Operator Cash Flow by Corridor 2007 - 2027 (Millions of 1994 Dollars)

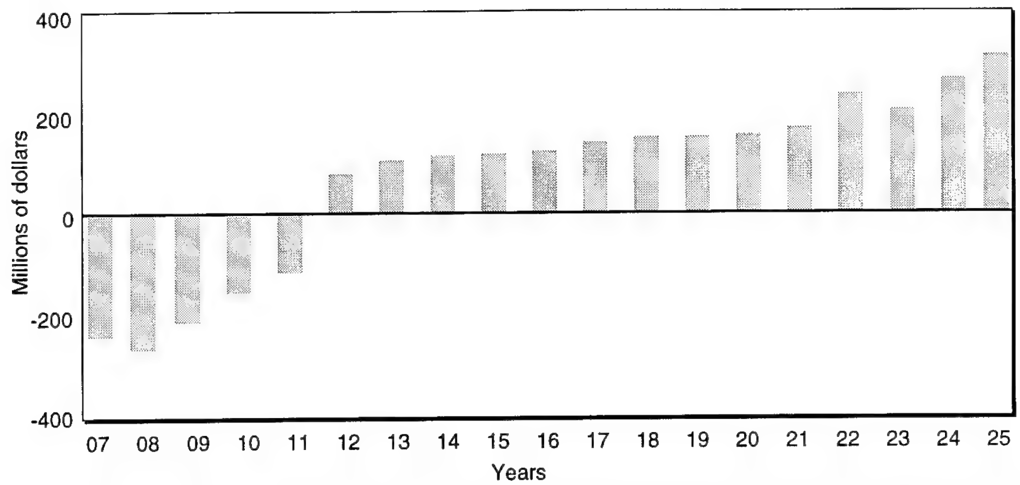


Figure E7.1-2 Annual Cash Flows From CTR Operations in Four U.S. Corridors For 20 Years (Millions 1994 Dollars)

Corridor	IRR	NPV
Northeast	11.7%	$21 million
Midwest	11.6%	$11 million
West Coast	8.5%	$1 million
Southwest	11.1%	$(6) million

Figure E7.1-3 After-Tax IRR and NPV at 10 Percent

Aircraft Selling Price	Operator	
	NPV at 10 percent	IRR
$18.5 million	$27	11%
$17 million	$122	16%

Figure E7.1-4 Sensitivity Summary

E7.2 Airline Perspective

E7.2.1 General Observations

Airlines require a high degree of certainty on CTR performance, costs, and market potential before they will invest in this vehicle. Their concerns include:

- The availability of infrastructure, including vertiports and air traffic control (ATC), at a reasonable cost.
- Vehicle operating cost, including fuel consumption and maintenance.
- Vehicle reliability.
- Passenger acceptance.
- CTR operating profitability.
- Ability to sell CTR vehicles if market does not work out.

Airlines view CTR as an aircraft for which no real-world operational experience exists, and a new aircraft designed for a market that they believe is already well served with existing aircraft. Airlines tend to discount CTR capability to fly to demand centers at vertiports because no vertiports currently exist and only a few are on the drawing board. At the present time, there are too many unknowns about acquisition and operating costs of CTR, as well as its reliability in scheduled passenger service, to generate strong airline interest in this technology. Airlines may perceive greater downside risk regarding purchase of CTR aircraft because there may be no alternative market for resale of unneeded aircraft as there is for jets or turboprops. In addition, some could argue that some degree of congestion actually benefits the airlines because it is an indicator of scarce capacity. Airlines might benefit from this scarcity through the ability to charge higher airfares. For example, the

General Accounting Office (GAO) estimates a fare premium of 4 percent for slot-controlled airports (reference 20).

E7.2.2 Airline Executive Interviews

Existing airlines are most interested in recovering from the past few years in which they suffered unprecedented losses. Most carriers are returning to profitable operations and are now seeking to strengthen their balance sheets so that they are capable of financing needed investment such as replacement aircraft. Their focus is necessarily short term, and they find it difficult to speculate on likely market conditions 10 to 15 years in the future when CTR aircraft would come into use. Nevertheless, the Civil Tiltrotor Development Advisory Committee (CTRDAC) felt it was important to determine the airline view of CTR aircraft.

New start-up airlines generally begin operations with used aircraft and are capital constrained. CTR represents a high entry cost strategy because only new vehicles would be available for a number of years. In addition, most new entrants seek to exploit their inherent cost advantage over existing carriers and pursue low-fare strategies. To be successful, a CTR system must attract the most time-sensitive passengers who would be willing to pay more than the prevailing fare to save time. As such, the likely marketing approach for CTR most clearly resembles the market segmentation strategy used by FedEx (formerly Federal Express) when it first entered the overnight package business. FedEx delivered a premium service and charged prices above those for normal air cargo. Although FedEx had to build the pickup and delivery network, it did have access to used aircraft and existing airports. CTR not only requires new vehicles, but also new infrastructure, i.e., conveniently located vertiports.

Airlines would require significant assurances on CTR performance, costs, and market potential before they will invest in CTRs and start service. Their concerns include:

- The availability of infrastructure, including vertiports and ATC, at a reasonable cost
- Vehicle operating costs, including fuel consumption and maintenance
- Vehicle reliability
- Passenger acceptance
- Limited secondary market for CTR aircraft

At the present time, there are too many unknowns about CTR acquisition and operating costs, as well as CTR reliability in scheduled passenger service, to generate strong airline interest in this technology. Airlines also may perceive greater downside risk regarding purchase of CTR aircraft because there may be only a limited secondary market for used CTRs.

Finally, most of the delay reduction benefits produced by CTR would not accrue to the operator of CTR aircraft, but to airlines and air passengers in general.

Interviews were conducted with executives of Southwest Airlines and FedEx to determine industry reaction to the CTR concept and to provide additional insight into issues that might require further research and development in order to gain carrier acceptance.

Within its current corporate structure, Southwest Airlines did not express an interest in operating CTR aircraft. Their current philosophy is to operate a single, low-cost aircraft type and its derivatives in frequent, low-cost service. They expressed the belief that CTR is oriented towards the premium end of the market which is not the market segment that they are currently approaching.

Like Southwest Airlines, FedEx has a limited interest in operating CTRs, although they requested that they be kept informed of CTR development. They noted that the only significant role they saw for CTR at FedEx was in a small number of congested urban markets or if they sought to establish same-day package express service.

In addition to interviews with Southwest Airlines and FedEx, American Airlines was represented on the CTRDAC Economics Subcommittee along with representatives from two Wall Street

firms active in aerospace and airline finance. These individuals indicated that they expected little near-term interest in CTR from airlines because airlines are currently concentrating on restoring the profitability of their existing operations. They also thought that some existing airlines might view CTR as a competitive threat. While this explains the lack of airline interest, it does not offer substantial insight on the economic viability of a CTR service to be introduced in 2007, other than to emphasize the difficulties of starting up a new transportation system.

The financial community indicated that any sort of air transportation-related financing ranks poorly compared to other private sector industries, owing to the low rates of return on investment in the air transportation industry. CTRs could be financed in the private sector, but it would require interest rates reflecting the low potential returns and the large downside risks associated with the lack of a secondary market for CTR vehicles.

E7.3 Passenger Perspective

Throughout aviation history, new aircraft concepts have been met with both positive and negative reactions. For example, when the first jet-powered airliners came into service, there was some concern about the lack of a visible propulsion source. However, once the benefits of lower price, reduced travel time, and increased comfort were realized, the new technology was embraced and hailed for its contributions.

As with the jet airliner 40 years ago, the unorthodox appearance of the tiltrotor vehicle suggests that the question of passenger acceptance must be considered when investigating whether or not it will become a widely accepted form of air transportation. Potential customers may have certain reservations concerning the safety and reliability of such an unusual looking vehicle. It is, therefore, very important to find out what passenger perception of CTR is before any investments in production are made.

E7.3.1 Focus Groups

As part of a study performed by Charles River Associates Inc. (CRA) and Solomon & Associates, focus groups were conducted to determine traveller preferences concerning travel modes for intercity trips as well as problems and concerns associated with such trips. The methodology was to interview recent intercity travelers, who are the individuals most likely to use CTR service and determine how the public would react to the introduction of CTR. The individuals selected were based in two of the four prospective vertiport location areas, Washington D.C. (in the Northeast corridor) and Chicago (in the Midwest). Along with examining their willingness to use CTR, the surveys also raised several issues related to CTR infrastructure, including vertiport siting and accessibility, airport preferences, travel mode replacement by CTR, and prices of CTR services.

E7.3.2 Passenger Travel Mode Preferences

For the focus groups, questions of travel mode preference centered primarily on air and auto travel. Passenger rail was also mentioned, but this mode was limited to the Northeast corridor and was preferred only on the Philadelphia to Washington D.C. segment. The focus group members chose to fly if they were on a business trip that would last only a day or two. If the trip was to last more than two days or the trip was with family or for personal reasons they were more likely to drive. This attitude primarily reflected the increased flexibility gained from having a car at the destination without renting one. In addition, distance was a factor mentioned in the question of travel mode choice. The farther away the destination, the more likely the respondents were to use air travel.

A second consideration in travel mode preference voiced by the focus group members was cost. In both business and leisure travel, respondents maintained that they look for discounts and lower prices when considering travel modes. During price wars and advertised discounts, many focus group members shifted from driving to air travel.

In addition, many were more prone to take unplanned trips when reduced fares were available. Also, air travel was seen as less stressful and faster than driving for a majority of travelers.

A third and perhaps most pertinent issue with regard to CTR was the accessibility of airports in the Chicago and New York areas. The problems associated with airport access times led a number of focus group members to indicate that they would substitute driving or, in the New York area, use the train. The congestion associated with these airports, along with long access times and the size of the airports, contributed to the belief that they can be very stressful places for passengers.

E7.3.3 Airport Preferences

Airport preferences were also discussed in the focus groups. The most important considerations in airport choice were price and the convenience of getting to and from a particular airport. Many of the focus group members were aware of available low fares at certain airports and made efforts to take advantage of them. The overall cost of a trip was considered by some focus group members, although this concern was more important for personal travel than for business travel. A second airport preference factor was airport access. This was an important concern for business travelers and for flights within the intermediate distances that are being considered for CTR operations. Airport size was a definite consideration in deciding which alternative site to choose.

E7.3.4 Passenger Perspectives of CTR Vehicle

The reaction to CTR was mixed. Some focus group members were excited by the concept of a completely new aviation vehicle and expressed an interest in using it once it was introduced into scheduled service. Some people expressed excitement about flying in small planes and were ready to try CTR immediately. However, the most important aspect of the focus group response was the potential convenience of a nearby vertiport at both the origin and destination. The possibility of a reduction in access time was viewed very positively by the focus group members, especially business travelers. Because these individuals placed a high value on their time, a reduction in total travel time for them was very important in travel mode choices.

Three specific problems were cited by some focus group members: (1) the size of CTR, (2) the noise they assumed would be generated by the vehicle, and (3) the effect of CTR on safety and the U.S. ATC system.

Because a CTR is smaller than a jet, its safety was viewed as being comparable to that of a commuter aircraft. The negative perceptions respondents had regarding commuter aircraft safety were transferred to CTR. Several felt that they would be more comfortable using CTR once it had been in service for several years and had maintained a positive safety record. Government certification was not viewed as sufficient to allay their concerns about safety. Concerns were also expressed about the lack of interior space available in commuter-type aircraft. Another concern was over the noise they assumed would be generated by CTR. In this regard, CTR was compared to a helicopter, which several focus group members had heard at low altitudes and thought were rather loud. Based on these assumptions, there was concern over the possibility of increased noise pollution due to the addition of CTR to the transportation system. Finally, concern was expressed over the potential for added congestion and ATC problems with the addition of CTR flights. Once again the question of safety arose with the thought that additional CTR operations would increase controller workload and lower safety levels due to an increase in aircraft in the air for the same number of passenger miles.

Focus group members were also asked about their preference for CTR versus high-speed rail. The latter was a somewhat more familiar concept to most focus group members, and they seemed to be slightly more comfortable with it. Most felt that high-speed rail would be safer and more comfort-

able than CTR. However, some focus group members felt that CTR would have advantages over high-speed rail in reduced travel time and convenience, with more or more conveniently located terminals.

E7.3.5 Conclusions

In spite of their concerns regarding CTR safety, over 80 percent of the focus group members expressed interest in using CTR once it was introduced. The reduced access times to and from proposed vertiports were considered to be a tremendous advantage over existing travel choices. Therefore, vertiport location and convenience will be a major factor in the success of CTR. It should also be noted that a majority of the focus group members felt that CTR would be primarily suited for business travel. However, a large minority thought non-business users would choose CTR if it met their specific trip needs. Finally, most focus group members concluded that they would be comfortable paying as much as $25.00 more for a one-way CTR trip if convenient vertiport locations reduced their need for expensive ground access transportation.

E8.0 Vertiport Economics

E8.1 Introduction

An important consideration in the potential use of civil tiltrotor (CTR) technology is vertiport economics. Costs have been examined at two levels. The first level involves the individual facility itself, whether a stand-alone vertiport, a separate facility on an airport, or modifications to existing runways and terminal facilities at an existing airport. The second level of cost is for a complete system of vertiports. Also addressed are potential revenues that can be expected to be derived from the vertiport and how well these revenues meet the cost of its development and operation.

E8.2 Vertiport Costs

Figure E8.2-1 presents a generic range of costs for several types of vertiports at typical locations as provided by the Civil Tiltrotor Development Advisory Committee (CTRDAC) Infrastructure Subcommittee. The costs are based on the size of specific vertiports, the expected number of passengers, location (urban, suburban, or airport), and type (elevated, ground, pier). Typical land costs are included.

Location	Type	Cost Range (in millions of dollars)
City center	Elevated vertiport	10 to 40
	Vertiport on new pier	90 to 125
Suburban	Ground vertiport	6 to 20
	Elevated vertiport	10 to 25
Airport	Existing facility	0 to 10
	New airside facility	2 to 17

Note: Cost ranges do not include the cost of noise or environmental mitigation

Figure E8.2-1 CTR Generic Vertiport Cost Range

Representative vertiport networks were defined that satisfied projected CTR passengers in the four U.S. corridors. Figure E8.2-2 shows the number and types of vertiports in these representative networks. Overall, 27 vertiports would be required. Based on a review of available facilities and local demand studies, 14 of these vertiports could be located at existing airports. All vertiports at airports are assumed to be ground-level facilities except for the vertiport located at National Airport in Washington, D.C. Two vertiports were assumed to be located on piers or barges.

Corridor	Ground Level	Elevated	On Piers	Total	At Existing Airports
Northeast	6	3	3*	11	7
Midwest	3	5	0	8	3
West Coast	3	3	0	6	3
Southwest	1	1	0	2	1
Total	**13**	**12**	**2**	**27**	**14**

* One pier/barge vertiport considered for the start-up system would be eliminated in a final system

Figure E8.2-2 Estimated Vertiport Requirements

A full network of large, sophisticated vertiports will not spring into existence all at once. The concept of a start-up system recognizes this fact. Establishing a start-up network will minimize the initial investment while demonstrating how such a network can be achieved. With proper coordination and timing, this will also provide assurance of the availability of infrastructure and enable the manufacturers to make a commitment to build the 40-passenger CTR.

CTR ground infrastructure cost estimates (figure E8.2-3) were developed by the Infrastructure

	Vertiport Cost	Automobile Parking	ATC/ Navigation	Total Cost
Startup	50	11	6	67
Mature	487	70	42	599
Total	**537**	**81**	**48**	**666**

Figure E8.2-3 Estimated CTR Ground Infrastructure Costs for Four U.S. Corridors (in Millions of Dollars)

Subcommittee for a start-up system and a mature system. The total cost of both is estimated at $666 million, including $48 million for towers and related air traffic control (ATC) and navigation facilities. In addition, the estimates include over $80 million for automobile parking facilities. These cost estimates do not include improvements to highway or rail access systems.

Costs for noise or environmental mitigation measures are site specific and extremely difficult to estimate and are not included. Vertiport development costs are significant, but, by comparison, a single instrument flight rules (IFR) runway with associated lighting and navigation equipment at a major airport can cost $80 to $500 million.

E8.3 Vertiport Revenues

Revenue can be generated from aeronautical vertiport users based on rent, landing fees, space rentals, or other comparable charges for the use of vertiport facilities. Other potential sources of revenue include fuel sales, aircraft maintenance, and hanger fees.

Historically, approximately 27 percent of the 10 percent aviation ticket tax is returned to the airport system through Airport Improvement Program (AIP) grants. These funds may be used to repay the land acquisition, construction, and development costs. In future legislation, vertiports will probably be treated in a manner similar to airports.

Non-aeronautical revenues consist primarily of revenues from parking and concessions, such as restaurants, retail shops, rental cars, wall advertising space, and airport hotels. Vertiport concession revenues are expected to be significantly smaller than those at conventional airports. However, parking fees might be a source of revenue for vertiports, particularly in suburban locations. The availability of these various revenue sources is dependent on the location and character of a particular vertiport.

E8.4 Vertiport Financing Sources

This section describes a variety of financial alternatives, including several traditional methods of financing airport improvements. In order to obtain funding, it will be crucial to convince the involved entities of the feasibility, viability, and benefits of the vertiport program. Various methods of financing may be used in combination.

- *Federal Airport Assistance*

Under current legislation, vertiports would be eligible for AIP funding available from the Airport and Airway Trust Fund with revenues derived from user taxes. Currently, vertiports are eligible for formula-derived enplanement funds after they have a sufficient number of annual passengers. Federal airport aid programs have been ongoing for the past half century. The continuation of Airport and Airway Trust Fund user taxes is subject to future Government policy.

- *Passenger Facility Charges*

Passenger facility charges (PFC) are fees imposed by commercial service airports on each paying airline passenger enplaning at that airport. PFCs are considered local funds, not Federal grants, although Federal Aviation Administration (FAA) approval is required to impose and use the fees collected. To date, the FAA has approved the imposition of PFCs totaling $11.24 billion for current and future projects.

Vertiports would be eligible for PFC funding under the same criteria as airports. In a start-up scenario, a vertiport may not immediately have sufficient passenger service to justify the imposition of a PFC. However, the vertiport could be funded from PFCs imposed at an airport or other facility if it were under sufficient control of a public airport agency with PFC authority.

• *Other Federal Grant Programs*

In addition to AIP grants, there may be grant funds available through other agencies for the infrastructure required to support a vertiport. For example, access roads could be funded through Federal Highway Administration (FHWA) programs and mass transit systems could be funded through Federal Transit Administration (FTA) programs and the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. However, these programs have historically put a low priority on airport access projects.

• *State and Local Government Programs*

State and local government programs represent another possible source of funding. These funds may be used for aviation-related projects, but may also be designated for infrastructure necessary for vertiport development. Local governments can use tax-exempt financing methods such as bonds or other tax incentives to foster vertiport development.

• *Bonds and Tax Incentives*

Bonds are a form of financing available to both the public and private sector. Public sector bonds are ordinarily tax exempt, while private sector bonds are not. However, the private sector may enter into an arrangement for tax-exempt financing of private ventures under certain conditions. Tax-exempt financing is a common method by which local governments provide financing for airport development. Consequently, vertiports that are publicly owned and for public use would arguably be eligible for tax-exempt financing.

Tax incentives may be another method of enhancing the economic feasibility of this type of project, much like grants, PFCs, or contributed capital that would constitute "equity."

• *Private Grants and Gifts*

Governmental entities may occasionally receive grants or gifts of property from the private sector to construct new infrastructure, which would be owned by the governmental entity and used for a public purpose. The motivation of the private sector grantor may be to increase property values or the marketability of its own enterprise. One example would be for a private sector party to contribute to the development of a vertiport because that party owns land and/or office buildings that would be adjacent to the new vertiport.

• *Public/Private Partnerships*

Public/private partnerships would probably require the governmental entity to act in an entrepreneurial capacity, rather than in its traditional sovereign capacity. The facilities developed under financing arrangements of this type would still need to be used for a public purpose.

Such a partnership would involve a contribution from each of the organizations involved. The Federal contribution could be management personnel and the funds required for detailed planning of each of the vertiport networks. The contribution from the states, metropolitan governments, and industry could be in the form of labor and the standard AIP state and local matching funds.

Whatever their source of revenues, most large airport projects typically make use of bond market financing for construction costs. Even for projects which can be fully self-sustaining with landing fee revenues, there is still a need for pay for construction prior to earning those landing fees. For this reason, the financial community will have a large interest in the potential viability of vertiports and whether they will generate sufficient income to service their debt. Initially, vertiports are likely to be viewed as risky investments by the financial community, because there is no history of vertiport or CTR operation. It may be necessary, therefore, to tie the vertiport to a port or airport operator to provide guarantees on debt service. If, for example, the airports that benefited from CTR congestion mitigation imposed PFCs to pay for vertiports, the financing community could be likely to look more favorably on vertiport financing.

E8.5 Vertiport System Financial Analysis

To repay the capital outlays outlined above and support ongoing operations and maintenance expenses, vertiports need to generate significant amounts of revenue. The primary sources for these

revenues include CTR operators; landing fees and other charges; and PFCs or AIP allocations from the 10 percent ticket tax. Whether sufficient revenues might exist to offset anticipated expenses depends on assumptions concerning the availability of Federal airport funding mechanisms.

Five scenarios were analyzed assuming the most likely combination of future financing alternatives for airports and, by default, vertiports:

- Existing AIP formula allocation funds.
- $3 PFC with no AIP formula allocation funds.
- $3 PFC with 50 percent AIP formula allocation funds.
- $4 PFC with no AIP formula allocation funds.
- $4 PFC with 50 percent AIP formula allocation funds.

These assumptions reflect the uncertainties over the future of AIP funds and the prospect for an increase in PFCs. If AIP funding is reduced, additional sources of vertiport revenues will be required. These might include passenger PFCs, increased operator contributions, increased concession or parking revenues, or local funding.

Other key assumptions include:

- Parking is self-financing. The construction, operating, and financing costs for vertiport parking can be recovered entirely from parking fees with no cross-subsidy to or from other vertiport activities. This reduces the total construction expenditures by $81 million.
- Other construction costs totaling $58 million are excluded from total construction expenditures. This includes $9.4 million in public/private partnership, $6.5 million in Government equipment, and $42 million for towers.
- The total construction cost for vertiports, excluding financing costs, is reduced from $676 million to $537 million.
- Completed construction costs are financed with a 30-year mortgage at 7 percent beginning with completion of construction in 2011.
- Intermediate construction costs are financed each year as costs are incurred with interest capitalized. Interest is calculated assuming the full amount needed for the year is borrowed January 1, plus the ending balance from the previous year. When CTR operations begin in 2007, any revenues in excess of vertiport operating costs are used to pay down the balance in accumulated construction costs. This reduces the amount of a mortgage.

Depending on the revenue assumptions, which reduce construction financing costs in the years 2007 through 2011, the construction cost balance at the start of the 30-year mortgage ranges from $570 million to $640 million. Figure E8.5-1 shows the income statement for the completed vertiport system in a typical year under the five scenarios.

Scenario	30-Year Mortgage	Revenues				Expenses			Revenue Less Capital and O&M Costs
		Landing Fees	PFCs	AIP	Total	Mort-gage	Operat-ing	Total	
Existing AIP formula	615	51	0	35	86	50	41	90	- 5
$3 PFC with no AIP	637	51	29	0	80	51	41	92	-12
$3 PFC with 50% AIP allocation	569	51	29	18	98	46	41	87	+ 11
$4 PFC with no AIP	599	51	39	0	90	48	441	89	0
$4PFC with 50% AIP allocation	532	51	39	18	107	43		84	+ 23

NOTE: Estimates include landing fees and other operator charges at $125 per flight and vertiport operation and maintenance (O&M) costs at $2.10 per passenger. Revenues and costs from other activities such as automobile parking and use by other aircraft are not included.

Figure E8.5-1 Vertiport Income Statement for Typical Year (Millions of Dollars)

E9.0 CTR Delay Reduction Benefits

E9.1 Introduction

One of the major social benefits which would likely result from the introduction of civil tiltrotor (CTR) service is the reduction in delays at congested airports. Delay reductions could occur if airlines reduced the number of fixed-wing flights in proportion to the number of passengers diverted from jet and turboprop operations to CTR.

This chapter examines CTR delay reduction benefits. The MITRE Corporation was tasked to examine the delay reduction potential if CTRs were used to replace some conventional air travel in the four U.S. corridors. This chapter also looks at the potential benefits of using CTR at slot-constrained airports.

Analysis of airport delays is very speculative. There is no consensus on measuring the level of existing delays, and there is disagreement on methods to project delays into the future[13]. The difficulty arises, in part, because airport delay is a nonlinear function of hard-to-measure and unpredictable components such as future airline operations and airport capacity levels. Therefore, it is wise to view airport delay estimates as uncertain, although U.S. airlines report that delay imposes costs in excess of $3 billion per year on airlines and their passengers.

E9.1.1 Estimated Delay Reductions

To estimate delay reduction savings, two scenarios were compared, the "baseline CTR" scenario and the "without CTR" scenario. Estimated delay reductions are based on CTR demand for vertiport-to-vertiport plus feeder services in the four U.S. corridors. Transfer passengers are not included. For the case where aviation traffic levels, capacity, and delays were assumed to remain at 1993 levels, the delay analysis showed that daily operations at major corridor airports would be reduced by approximately 11 percent, or 650 flights, with CTR. Delay savings would average 0.3 minutes per operation at large U.S. airports, with the largest delay savings at airports in the Northeast (1.4 minutes per operation) and in the Midwest (0.5 minutes per operation). Figure E9.1.1-1 shows the distribution of technical delay reductions at all airports modeled and in each of the four corridors examined in the CTR market analysis for 1993 traffic and delay levels. The analysis shows that most of the delay reduction occurs in the Northeast and the Midwest. Figure E9.1.1-2 shows that these projections translate into annual delay savings of approximately $160 million in reduced aircraft operating costs, and $215 million in passenger delay cost savings when applied to all scheduled domestic air operations. Annual hours of aircraft delay saved were estimated at 120,000 hours.

For the case where airport traffic and capacity were assumed to increase in accordance with study assumptions and Federal Aviation Administration (FAA) long-term forecasts of seats, load factors, and use of commuter airlines for the year 2010, delay savings were estimated to average 0.8 minutes per operation with CTR. Figure E9.1.1-3 shows the distribution of technical delay reductions at all airports modeled and in each of the four corridors for traffic and delay levels in 2010. There are significant delay reductions projected in the Northeast, Midwest, and West Coast corridors. This occurs because air traffic operations growth in the corridor is projected to exceed airport capacity growth at several major airports in the region. As shown in figure E9.1.1-4, these delay savings represent approximately $1.35 billion in reduced air-

[13] Airlines and capacity analysts often refer to "technical" delay which is a measure of the excess flight time and costs incurred because of airport and ATC capacity limitations. Because of on-time reporting requirements for airlines, much of this technical delay does not appear in published delay data.

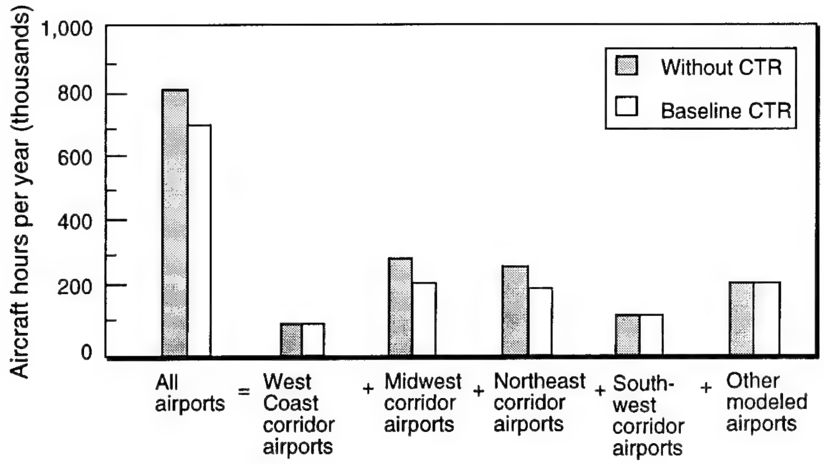


Figure E9.1.1-1. Projected 2010 Delays at 1993 Airport Congestion Levels

Type	2010 Annual Value of Delay Reduction
Aircraft operations	$160 million
Passenger time	$215 million
Total	**$375 million**

Figure E9.1.1-2 Annual Delay Savings Estimate From CTR Activity – Projected 2010 Traffic and Congestion Levels Using 1993 Delay Rates

Type	2010 Annual Value of Delay Reduction
Aircraft operations	$500 million
Passenger time	$850 million
Total	**$1350 million**

Figure E9.1.1-4 Annual Delay Savings Estimate From CTR Activity – Projected 2010 Traffic and Congestion Levels Using 2010 Delay Rates

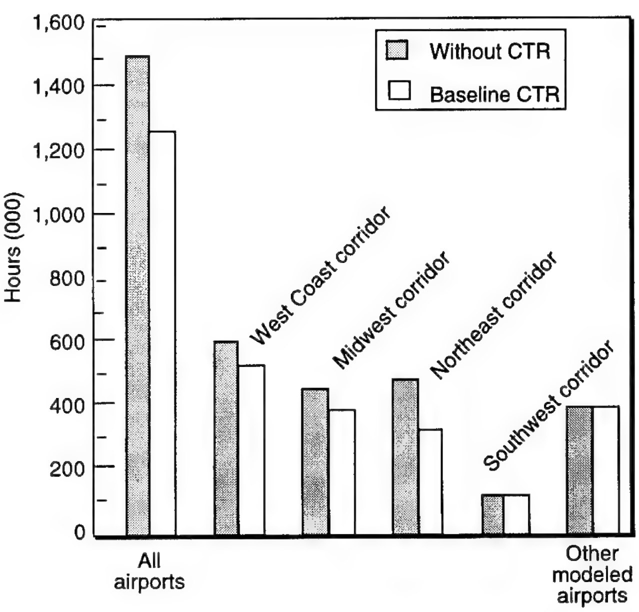


Figure E9.1.1-3. Year 2010 Delay Rates at Year 2010 Projected Traffic and Congestion Levels

craft operating and passenger delay cost savings. Annual hours of aircraft delay saved were estimated at 325,000.

The estimated level of delay reduction would be lower if CTR service did not generate as much demand as projected or if fewer fixed-wing airline flights were removed from busy airports. For example, the analysis suggests that if introduction of CTR resulted in only half the baseline estimate of flights removed from major airports, projected airport delays would be reduced by approximately 40 percent. On the other hand, delay savings would probably be higher if diversions of transfer passengers were added to the analysis.

Figure E9.1.1-5 shows the total delay savings from CTR activity in 1993 and 2010 by traffic type.

Base Year Delay	Vertiport-to-Vertiport Plus Feeder Traffic	Transfer Traffic	Total
1993	375	185	560
2010	1,350	775	1,925

Figure E9.1.1-5 Delay Savings Estimates From CTR Activity by Year and Traffic Type (In Millions of Dollars)

E9.1.2 Limitations

There are several reasons why the baseline delay analyses might tend to overstate delay savings, especially when the 2010 FAA terminal area forecasts are used. These forecasts should be considered as an upper bound on the delay benefits that might follow the introduction of CTR service. First, the delay analysis included only near-term aviation technology improvements and planned airport capacity expansions until 2005 and did not include long-term capacity enhancement impacts.

The second reason is that the delay analysis did not systematically consider airline responses to increased airport delay and CTR competition. It is possible that airlines would either raise fares to reduce passenger demand or switch operations to less congested airports before delays at any given airport became excessive. This would likely result in lower average delays, but potentially higher CTR market share. Also, the assumption that fixed-wing aircraft would be removed from airport operational traffic streams without replacement is not likely to be true in all cases, especially in congested and slot-controlled airports[14]. If the airlines decided to substitute new flights (e.g. to other destinations) for some of the flights made eliminated because of CTR competition, or if they attempted to maintain existing flight frequencies by substituting smaller aircraft, much of the delay savings might not materialize. However, this would result in additional airport capacity.

The substantial delay reduction benefits of CTR should be placed into context. These benefits would accrue to a diversity of aircraft operators and air passengers. More importantly, only a small portion of these benefits are likely to accrue to carriers which acquire CTR aircraft. There also are a number of other actions which may be effective in reducing some or all existing delays, including:

- Use of larger aircraft, increasing load factors, or changes in pricing.
- Air traffic control (ATC) system improvements, particularly those which increase airport capacity in instrument flight rules (IFR) weather conditions.
- Development of additional airport capacity through improved operational procedures, the construction of new runways, and development of new airports.
- Demand management strategies, including the use of appropriate prices for ATC or airport capacity to alleviate congestion.

However, to the extent these policies result in prices for conventional air transportation which more closely reflect optimal levels of delay, this would serve to make CTR more price competitive.

E9.2 CTR at High Density Airports

E9.2.1 Introduction

Demand for CTRs may be particularly strong at airports which have capacity constraints that prevent the addition of new flights at specific times without eliminating an equal number of existing flights. In the U.S., there are four such capacity-constrained airports that are governed by the FAA operational regulation called the High Density Rule (HDR). They are Washington, D.C.-National (DCA), O'Hare (ORD) in Chicago, and LaGuardia (LGA) and Kennedy (JFK) in New York.

If CTRs were used in markets served by HDR airports, a primary benefit would be to free up jet and/or commuter slots. It is uncertain that the adoption of CTR would ultimately lower overall congestion at these airports because the vacated

[14] The social benefits of increased intercity passenger capacity, as might result from introduction of civil tiltrotor service, might be as important as the benefits derived from delay reduction.

slots could be filled by other flights. Carriers who do not meet certain minimum usage requirements ultimately can have their slots given to a different carrier who would initiate new flights. Even if this were to occur, however, the additional air service provided in the introduction of CTR would still be a positive social benefit.

To assess the demand for CTRs at HDR airports, information was used on the profitability of flights on a carrier/city-pair specific basis for each HDR airport. This information was obtained from a previous analysis of HDR airports conducted for the Department of Transportation (DOT) and FAA (reference 21). In particular, the HDR study identified specific incremental flights that would likely be flown if additional slots were available at the HDR airports. Data on travel prices and costs were also obtained from this study. Details on the HDR price and cost methodology are presented below.

E9.2.2 Price and Cost Estimates at HDR Airports

In the HDR study, the "price" of service in each city-pair market was defined as the average money fare plus the value of service time. Service time was defined as travel time plus schedule delay. The inclusion of travel time reflects the fact that consumers value the time spent travelling between two points. Schedule delay refers to the gap between a desired departure time and the departure time actually chosen.

For purposes of this analysis, the money fare in each market was calculated as the average, carrier-specific fare shown in the DB1A ticket sample for the period 1992Q4 through 1993Q3. The DB1A fare includes tax and, therefore, represents the total relevant money price faced by consumers. Travel time was measured as the average scheduled block hour time in each market, as calculated from Official Airline Guide (OAG) data.

Schedule delay can not be observed directly because it depends on the desired distribution of demand over the course of the day. However, estimates were obtained using the following approach. It was considered to be reasonable that carriers at non-HDR airports, where operations may be scheduled whenever desired, attempt to schedule flights at the times when passengers actually wish to fly. To determine the distribution of demand for the four HDR airports, a corresponding non-HDR airport was chosen. Domestic operations at Boston (BOS) were used to determine demand at DCA and LGA. Washington, D.C.-Dulles (IAD) was used for JFK. Dallas/Ft. Worth (DFW) was used for ORD.

Separate distributions were derived for arrival and departure times. However, a single distribution curve across all markets from a given airport is probably not representative of the demand distribution for individual markets since the latter may vary according to both length of flight and perhaps changes in time zones. Thus, distribution curves were constructed based on eight different mileage blocks and four different time zones for each of the non-HDR airports used. The total daily demand in each market at an HDR airport was then distributed according to the relevant mileage block/time zone category to which it belongs.

With estimates of market-specific desired flight distributions, it was then assumed that passengers on each carrier would simply pick the nearest available flight to their desired departure or arrival time. Because passengers may actually switch carriers when schedules change, this may tend to overstate schedule delay. The analysis used the actual schedule of flights available on a representative day, August 11, 1993.

If additional slots were available at the HDR airports, it cannot be known for certain how many additional flights would be scheduled nor when they would be scheduled over the course of the day. For present purposes, it was assumed that carriers would add flights according to "best estimate" projections. Details are provided in the HDR study conducted for DOT and FAA. Furthermore, it was assumed that each carrier would schedule flights so that average schedule delay is minimized across all its passengers in each market given the desired

demand distribution. In reality, carriers would not likely be able to minimize schedule delay in each individual market given other scheduling constraints. This underestimate of schedule delay will tend to offset the overestimate described in the preceding paragraph.

With estimates of fares, travel times, and schedule delay in hand, the calculation of the full price of travel (FPT) was computed as FPT = fare + (1.7 wage x TT) + (0.15 wage x SD), where "wage" equals hourly wage, "TT" equals travel time, and "SD" equals schedule delay. Travel time and schedule delay are measured in hours. This equation is based on results from an econometric analysis of airline demand by Morrison and Winston (reference 22).

Next, an estimate was developed of the passenger demand in each market that corresponds to the OAG schedule for August 11, 1993. To accomplish this, passenger counts were tabulated from T-100 submissions, representing monthly totals of the actual number of passengers flown between two points by a given carrier. Transforming this monthly actual demand into an average weekday demand corresponding to August 11 required a number of steps. First, to account for the possibility that some scheduled flights may not have been flown, the actual passenger counts were multiplied by the fraction Scheduled Flights/Actual Flights. Both scheduled and actual flight counts are contained in the T-100 data. Total weekday demand was then estimated by applying the fraction Weekday Seats/Total Seats. Dividing by the number of weekdays in the month then resulted in an estimate of the average weekday demand based on the scheduled service offerings.

E9.2.3 Demand Curve

A change in the full price of travel, including travel time components, in any given market will result in a change in passenger demand. A demand curve was constructed to reflect this relationship. For existing markets where new flights would be added if slots were available, the full-price demand curves were based on changes in schedule delay implied by the FPT formula and the corresponding break-even load factor for the new flights[15]. A straight-line demand curve was then constructed which connected the "actual" FPT/quantity point with the projected new one.

The load factor calculation assumed that when a new flight is added, it is a "generic" flight with seats equal to the average seat size of existing flights in the market. To calculate costs, data from Form 41 submissions were used to obtain estimates of total aircraft cost per seat-block-hour for each aircraft type used on each route. This estimate incorporates both direct flight costs and indirect overhead costs. In addition, estimates of passenger-related costs per revenue-passenger-mile (RPM) were used.

For new markets where new flights are projected, the individual city-pairs were assigned to one of five categories based on distance and region of the country. Average revenue and cost figures per seat-mile were then developed for each category based on current existing flights. These figures were then used to compute producer and consumer surplus estimates for new flights based on the assigned category for each such flight.

Producer welfare is measured as net profits, that, in turn, are equal to revenues minus fully allocated costs. Carrier revenues in each market were computed as the average money fare described earlier, excluding tax, multiplied by the number of passengers carried in the market.

Carrier costs were divided into two components, passenger-related costs and aircraft-related costs. It was assumed that passenger-related costs were comprised of sales and promotion costs plus passenger servicing costs as reported on Form 41. Estimates of average passenger costs per RPM were then developed for each carrier.

All remaining operating expenses were treated as aircraft-related costs, and an average cost per seat-block-hour was computed for each major aircraft type for each carrier submitting Form 41

[15] All additional flights are assumed to "break-even" on a fully allocated cost basis.

financial data. A primary aircraft was then assigned to each market in order to compute total aircraft-related costs.

With price and cost estimates in hand, new flights were combined with already existing flights to form a set of "potential" flights for each carrier at each airport. Flights which could possibly be flown with CTR were then identified based on city-pair distance and average seat capacity in each market. Specifically, flights in those markets of less than 500 miles and where aircraft size averaged less than 50 seats per flight were identified as possible CTR flights. It was assumed that the potential revenues from flying such flights using CTR would remain constant, while costs were based on a regression curve developed from assumed CTR operating costs including ownership costs per seat mile for a range of distances as supplied by the Volpe Center. This is shown in figure E9.2.3-1.

Nautical Miles	Cents
50	61.9
100	44.4
200	31.9
300	26.3
400	22.9
500	20.6

SOURCE: Volpe National Transportation Systems Center

Figure E9.2.3-1 Total CTR Operating Costs Per ASM

A maximization problem was then formulated for each carrier, in which the carrier attempts to maximize profits by choosing which flights would use regular aircraft and which would use CTRs with the restriction that the total number of non-CTR flights must not exceed the number of slots available to the carrier. It was assumed that all existing flights would continue to be flown, but that potential new flights may or may not be flown, depending on profitability. It is important to note that the estimated carrier costs used in the profit maximization do not include airport delay costs that may be affected by overall activity levels at the airport (e.g., takeoff/landing and runway delays).

The results for each HDR airport are shown in figure E9.2.3-2. CTR appears to have significant replacement potential at both DCA and ORD. The impacts at the two major New York area airports, LGA and JFK, are much more modest. There were no instances where it was projected that new flights would be flown by CTR aircraft.

Airport	Number Of Existing Flights ≤ 50 Seats, ≤ 500 Miles	Number of Existing Flights Switched to CTR	Number of New Flights Flown by CTR
DCA	158	37 (23 percent)	0
ORD	148	40 (27 percent)	0
JFK	234	2 (1 percent)	0
LGA	181	6 (3 percent)	0

Figure E9.2.3-2 CTR Demand at HDR Airports

The corresponding changes in economic welfare are shown in figure E9.2.3-3. These changes represent the net additions to producer and consumer surplus under the CTR simulation, and include the effects of the existing flights flown by CTR as well as new flights flown by conventional aircraft. In this figure, producer surplus refers to the profit generated by the additional fixed-wing

Airport	Producer Surplus	Consumer Surplus
DCA	23	37
ORD	12	142
JFK	2	5
LGA	1	24
Total	**39**	**208**

Figure E9.2.3-3 Total Annual Change in Economic Surplus Due to CTR Operation at HDR Airports (In Millions of Dollars)

flights made possible by CTR minus the change in profits from shifting existing flights to CTR.

Consumer surplus refers to the difference between the total value passengers receive from traveling and the total amount they pay for the service. In the present context, the estimates shown here reflect the change in consumer surplus that occurs due to CTR flights replacing fixed-wing flights and new fixed-wing flights being added. As new flights are added to existing markets, the full price of travel falls along the demand curve, leading to a rise in consumer surplus. Positive consumer surplus is also generated in new markets.

The relatively high consumer surplus estimates for Chicago are due to the fact that much of the new activity projected there involves flights to large international cities on large aircraft that affects large numbers of passengers.

E10.0 Economic and Social Viability of CTR

E10.1 Introduction

This chapter presents the results of the economic and social viability assessment of civil tiltrotor (CTR) production and operation in the U.S. This assessment is structured in a benefit-cost framework developed to assess government and private sector investments in aeronautics technology programs (reference 23). The methodology estimates the benefits and costs accruing to private parties and to society as a whole, including:

- *Additional Research*

This is assumed to be funded by Government agencies to reduce the risk of the introduction of CTR vehicles. An alternative case assumes that this research is entirely funded by the manufacturers. These two options are the end points of a variety of cost sharing alternatives. When Government pays for CTR research and technology development, the manufacturer rate of return on the program is higher.

- *Development and Production*

It is assumed that all development and production expenditures will be made by the manufacturer who also must finance the program negative cash flow in early years. It is assumed that enough vehicles will be delivered to U.S. operators to fulfill the market demand in 2010 with the remainder exported. The analysis shows that the manufacturer earns a real rate of return on program cash flows of 12 percent at 506 units delivered and a selling price of $18.5 million.

- *CTR Operations*

It is assumed that U.S. operators buy CTRs and operate them using the revenue, operating cost, and market penetration results developed in Chapter E4 of this technical supplement. Only the benefits and costs of U.S. CTR operations are included as benefits to the U.S. economy. At a selling price of $18.5 million, the real after-tax rate of return on operations is approximately 11 percent, although it varies among the four U.S. corridors studied.

- *Social Benefits and Costs*

The analysis also considers the delay reduction benefits and the costs of additional vehicle emissions as items that result from CTR operations but that are not reflected in the discounted cash flow of either the manufacturer or the operator. In the case of delays, the lower of the two MITRE delay projections, that assumes 1993 levels of airline traffic and delays, was used. However, no reduction delay benefits were assumed for CTR transfer traffic. The addition of social benefits results in an overall real social rate of return of approximately 16 percent, including the discounted cash flows to the manufacturer, the operator, and other airlines and air passengers from delay reduction. This estimate also includes the discounted cash flows from the increased CTR engine emissions.

The social benefit cost analysis does not include the additional producer and consumer benefits from using CTRs to reduce congestion at slot-controlled airports, because these duplicate, in part, estimated delay reduction benefits. The remainder of this chapter discusses these results in more detail. However, it first covers other potential economic and social benefits, as well as the intangible benefits and costs, of CTR production and operation in the U.S.

E10.2 Other Potential Economic and Social Benefits

A U.S.-led CTR manufacturing program could increase employment in the aerospace industry and improve the U.S. balance of trade. The exact magnitude of these benefits will depend on the

level of CTR production and the proportion of U.S. content of these vehicles. This section discusses these types of impacts.

E10.2.1 Employment

CTR production would create additional employment in the U.S. Measuring the effect on employment requires consideration of what alternatives these workers would have if a CTR program did not take place. In addition, employment effects should be considered net of any employment that occurs as a result of performing the transportation provided by CTRs using other modes. The analysis developed for the Civil Tiltrotor Development Advisory Committee (CTRDAC) Economics Subcommittee does not support the estimation of employment impacts at this level of detail. However, many of the CTR passengers are diverted from conventional airline services that are currently provided by both jet and turboprop airplanes. Nearly all current generation large turboprop aircraft are manufactured in foreign countries, although some do contain U.S.-manufactured engines and avionics. Jet aircraft are produced in the U.S., Europe, and Canada, although most programs are multinational in nature. The total employment associated with the production of 1,175 40-passenger CTRs is estimated to be 680,000 employee-years over a 20-year production period.

E10.2.2 Balance of Trade

Because it is assumed that CTRs will be produced in the U.S., export sales of these vehicles would improve the U.S. balance of trade. To the extent that a U.S. CTR program evolved with overseas partners, the foreign-produced content of the CTR should be excluded from export sales and included as a negative to the balance of trade for CTRs sold in the U.S.. However, as noted above, the correct measure of these effects depends, in part, on how the transportation missions would be performed if CTRs were not used. It would then be possible to determine the net effect on U.S. exports from a commercial CTR program. The analyses developed for the Economics Subcommittee are not developed to a level of detail to permit estimates of the net balance of trade effects. However, in the base scenario, it is estimated that total export sales of 40-passenger CTR aircraft are $17.8 billion in 1994 dollars over a 20-year production period.

E10.3 Intangible Benefits

In addition to the quantifiable national societal benefits that would result from creation of a CTR regional air transport system, there are qualitative benefits. Taken together with economic values, the total value from CTR technology goes beyond its use in short-haul passenger transportation. These benefits also could accrue were other sizes of CTR vehicles developed.

• *Retention of National Lead in Tiltrotor Technology*

The U.S. has developed the tiltrotor; other nations have not. As long as development and production continues, the U.S. will maintain an economically valuable lead over other nations in this aviation technology and retain an international trade advantage. There is no other aircraft product in the world with the enviable position of having no industrial competition.

• *Transportation Enhancement/Productivity Increase*

Increases in national/regional productivity might result from CTR services. For developing regions, CTR service could allow the decentralization of industry in smaller communities while retaining air access. CTRs could provide improved transportation for package express services, corporate travel, air taxi flights, and other sources of economic activity in addition to the short-haul passenger transportation missions considered in this report.

• *Disaster Relief*

A tiltrotor offers excellent capability for disaster relief from hurricanes, floods, and earthquakes under the Federal Emergency Management Agency (FEMA). Swift response and independence from runways that are often closed to airplanes in these

circumstances make the tiltrotor a valuable asset to carry medical teams, provide medical evacuation, and transport needed food, water, and emergency supplies. CTRs also could function as part of the Civil Reserve Aircraft Fleet (CRAF) program in which civil transports are equipped to operate for the Department of Defense in time of national need such as troop deployment during Desert Storm. CTR aircraft in regional service could be equipped to be available for diversion to national civil needs.

For the Coast Guard role of drug interdiction, a tiltrotor could replace the present combination of three different types of aircraft required for search, tracking, and apprehension roles. Coastal environmental surveillance, search and rescue, and patrol of border regions are additional public service missions in which a tiltrotor can perform better than either fixed-wing or helicopter alternatives due to its speed and vertical flight combination.

- *Resource Development*

National needs require that additional indigenous oil reserves be found and exploited. Such reserves exist but a lack of effective transportation alternatives affect their exploitation. Tiltrotors could be used in the exploration and development of oil reserves at greater offshore distances than is practical with helicopter support. Tiltrotor aircraft also offer the oil industry a unique and timely means to respond to the control or containment of oil spills at sea. Properly equipped tiltrotor aircraft could deploy to any point in the world and be on site in a matter of hours to help contain a spill at sea.

- *CTR/Military Operational Performance Feedback*

Since the first civil helicopters, the high utilization rates of civil fleets have resulted in lessons learned and improvements that were then applied to military helicopters. In a similar fashion, CTR aircraft will provide valuable lessons learned from service experience could be applied to V-22 aircraft in military service.

E10.4 Energy and Emissions

Energy and emissions impacts are two important societal consequences associated with the introduction of CTR service. The market analysis projects that CTRs will likely divert a substantial number of intercity passengers from other modes of transportation, principally from jet and turboprop air travel. Because CTR is expected to use different amounts of energy per seat-mile and produce different levels of emissions than other intercity passenger modes, the introduction of this new service will have implications for the total amount of transportation energy used and emissions released into the environment.

Estimates of energy and emissions impacts are based on projected changes in demand for CTR and other intercity passenger transportation modes, including changes in access/egress travel times and delays at conventional airports. Estimates are also based on modal energy intensities and emissions rates. The analysis assumed energy and emissions factors for typical jet and turboprop aircraft, as well as likely CTR engine capabilities.

Figure E10.4-1 presents information on the energy efficiency per seat-mile of CTR compared to jet and turboprop aircraft that might typically be in service in the early part of the next century. With expected improvements in engine design, CTR is projected to be about as energy efficient as modern turboprop aircraft in the same 35- to 60-passenger size range. However, CTRs will likely use more energy per seat-mile than a 130-seat Boeing 737-300. For example, at a typical range of 300 miles, the jet is estimated to use approximately 38 pounds of fuel per seat, while a typical turboprop or CTR are estimated to use approximately 50 pounds per seat, representing a 30 percent difference.

Figure E10.4-2 shows estimates of the changes in total energy consumption for the year 2010 after introduction of CTR service in each of the market areas studied. The data are for fixed-wing aviation activity between major metropolitan areas and corresponding CTR vertiport-to-vertiport plus feeder travel. The analysis assumed that energy

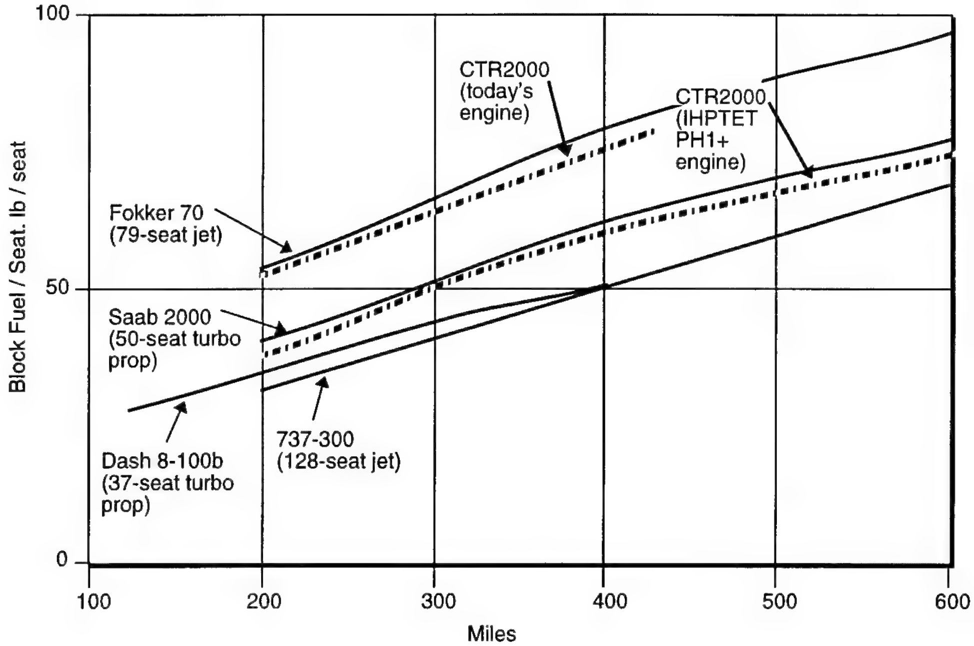


Figure E10.4-1. Comparison of Block Fuel Per Seat of CTR Versus Other Aircraft For Different Trip Lengths

Market Area	Prior Aviation Energy	CTR + Aviation Energy	Absolute Change	Percent Change
Northeast	107.9	127.8	19.8	+ 18.4%
Midwest	288.0	299.5	11.4	+ 4.0%
West Coast	228.7	233.1	4.4	+ 1.9%
Southwest	26.3	27.2	0.8	+ 3.2%
Total	**651.0**	**687.5**	**36.5**	**+5.6%**

Note: For vertiport-to-vertiport plus feeder travel (11.2 million passengers)

Figure E10.4-2 Estimated Changes in Aviation Transportation Energy Use After Introduction of CTR for Year 2010 (Millions of Gallons)

consumption of a Boeing 737-300 would be typical of jet travel for the year 2010, and that turboprop energy use could be approximated by the Saab 2000.

The largest increase in energy use is projected to occur in the Northeast corridor due to two factors: (1) the large, 20 percent estimated diversion of passengers to CTR in the Northeast; and (2) the substantial level of induced, or new trip, travel that accounts for approximately 9 percent of CTR passengers in the Northeast. On a passenger-mile basis, the estimated increases in energy use range from 1.8 percent in the West Coast corridor to 11.6 percent in the Northeast.

Calculated at $0.60 per gallon of aviation fuel, the estimated dollar value of increased energy consumption due to diversion of passengers to CTR is approximately $21.9 million in 1994 dollars in the year 2010. This averages approximately $2.10 per CTR passenger.

Offsetting the estimated increases in energy use for the line-haul portion of CTR trips are reductions in projected energy use for the access

and egress segments of these intercity trips. These energy savings are expected to occur because it is assumed that vertiports will be more conveniently located than existing airports. Figure E10.4-3 shows estimates of the access/egress energy savings and the combined access/egress and line-haul energy changes.

The access/egress energy savings are estimated to be only approximately 5 percent of the estimated line-haul energy consumption increases attributable to introduction of CTR service in 2010.

The rates of emissions per pound of fuel burned vary by engine technology and phase of flight. The CTR is projected to use an advanced, low-emission Allison T406+ engine which is expected to produce 40 percent to 50 percent lower emissions of oxides of nitrogen in all phases of flight and reduced carbon monoxide (CO) and hydrocarbon (HC) emission rates while idling (e.g., taxi in/out). Compared to the Boeing 737 jet engines, the CTR engine is expected to produce less emissions of oxides of nitrogen, but considerably more HC emissions per pound of fuel consumed.

Figure E10.4-4 shows estimates of the levels and dollar values of aviation emission changes resulting from the introduction of CTR vertiport-to-vertiport service in the year 2010. The estimated reduction in emissions of oxides of nitrogen is due to projected improvements in CTR engine technology. The monetized values of emissions changes are calculated using estimates of average control costs to reduce mobile and fixed point emissions by the best available existing technologies.

The estimated societal cost of added emissions due to CTR service in 2010 is approximately $5.3 million. This is approximately $0.50 per CTR passenger.

Market Area	Access/Egress Energy Change	Line-Haul Energy Change	Combined Absolute Change	Combined Percent Change
Northeast	- 0.8	+ 19.8	+ 19.0	+ 17.6%
Midwest	- 0.3	+ 11.4	+ 11.2	+ 3.9%
West Coast	- 0.5	+ 4.4	+ 3.9	+ 1.7%
Southwest	- 0.05	+ 0.8	+ 0.8	+ 3.0%
Total	**- 1.6**	**+ 36.5**	**+ 34.9**	**+ 5.4%**

Figure E10.4-3 Estimated Changes in Access/Egress Transportation Energy Use After Introduction of CTR for Year 2010 (Millions of Gallons)

Market Area	Change in Emissions (tons)			Dollar Cost (in millions)
	HC	CO	Oxides of Nitrogen	
Northeast	+68	+240	-202	+3.1
Midwest	+37	+130	-163	+1.8
West Coast	+18	+55	-98	+0.4
Southwest	+3	+10	-10	-0.02
Total	**+126**	**+435**	**-473**	**+5.3**

NOTE: for vertiport-to-vertiport plus feeder travel (11.2 million passengers)

Figure E10.4-4 Estimated Changes in Aviation Transportation Emissions After Introduction of CTR for the Year 2010

In addition to emissions and energy changes directly attributable to introduction of CTR, further environmental savings could be expected from reductions in delays at congested airports resulting from diversion of air passenger traffic to CTR. These savings would only be realized if delays were reduced during the in-flight or ground idling phases of flight, as engines are normally turned off when aircraft are at gate positions. Currently, the Federal Aviation Administration (FAA) estimates that airborne delays account for 29 percent of total delays, ground delays account for 64 percent, and the remainder taken as gate-hold delays.

The evaluation of delay at major airports suggests that as much as 0.5 minutes per air operation could be saved if CTR attained its highest demand potential and if airlines did not refill slots with new fixed-wing air operations. If only 50 percent of the baseline CTR demand were realized, the projected delay savings per operation would be approximately 0.3 minutes per operation.

The energy and emissions savings from airport delay reductions are estimated to be about the same magnitude or more than the added energy use and emissions resulting from substitution of CTR for jet and turboprop service. Therefore, if airport delay reductions are realized, the introduction of CTR service can reasonably be expected to be environmentally neutral. Even without significant airport congestion relief, the extra environmental burden associated with CTR use is estimated to be less than $5.00 per CTR passenger.

E10.5 Social Benefit/Cost Analysis

A discounted cash flow analysis composed of four modules makes up the CTR economic and social viability assessment. These modules include government research and development, manufacturing, operations, and delay plus environmental effects.

The research and development cash flow is assumed to begin in 1995 and spans 8 years with total expenditures of approximately $560 million. Private manufacturer development costs are assumed to begin in 2003 and cover a 5-year period with total expenditures of $1.2 billion. The first aircraft deliveries are made in 2007 and continue for 16 years with a total production run of 1,110 aircraft. As noted elsewhere, the unit price is taken to be $18.5 million and break-even occurs on the 506th aircraft based on a 12 percent rate of return. It is also important to note that any net losses are assumed to be expensed in the year of the loss for tax purposes. Based on these assumptions, the after-tax internal rate of return (IRR) of the manufacturer cash flow after the full production run is approximately 22 percent. This excludes the approximately $600 million research and development expenditure assumed to be undertaken by Government. If these costs were paid by the manufacturer cash flow, the full production IRR would fall to approximately 11 percent. If only 500 units were produced and the manufacturer paid the research and development costs, the IRR would fall from 12 percent to approximately 0.4 percent.

As discussed in Chapter E7 of this technical supplement, the operations cash flow is broken down by corridor for 2010. The base case scenario is used which includes vertiport-to-vertiport and feeder operations but excludes transfer operations. For each corridor, operations are assumed to begin in 2007 or later and ramp up to the demand projections in 3 to 4 years. The operations are then assumed to grow 1.5 percent annually through the end of the cash flow analysis in 2025. This is consistent with the average growth rate across all corridors shown in figure E4.1.4-2. In all cases, CTR aircraft are assumed to have a useful life of 15 years, after which they are replaced by new CTRs.

Under these and other operator cash flow assumptions discussed in Chapter E7 of this technical supplement, the after-tax IRR and net present value (NPV) at 7 percent for each corridor in the base case is shown in figure E10.5-1. Across all corridors, the overall IRR is approximately 11 percent. When operator cash flows are discounted at 7 percent to reflect the societal return, the NPV in 1995 is $175 million.

Corridor	IRR	NPV
Northeast	11.7%	$106 million
Midwest	11.6%	$56 million
West Coast	8.5%	$10 million
Southwest	11.1%	$4 million

Figure E10.5-1 After-Tax IRR and NPV at 7 Percent

These rates of return do not include the effects of delay reduction or environmental impacts. In general, the effects of delay reduction are positive and quite large, while environmental effects are negative but very small. For present purposes, the delay and environmental impacts based on the 2010 estimates were assumed to be proportional to operations in each year for each corridor. It is also important to recognize that these effects are for the U.S. only and do not include foreign impacts. The total net benefits of delay and environmental effects discounted at 7 percent is approximately $1.2 billion through 2027. Figure E10.5-2 summarizes the components of social returns in the Base Case scenario by corridor and type of benefit.

With the estimates presented above, it is possible to calculate the overall NPV of cash flows including Government research and development, manufacturing, operations, and delay and environmental impacts (figure E10.5-3). The resulting cash flow has an overall NPV of approximately $1.9 billion using the social discount rate of 7 percent and an IRR of 16 percent, suggesting relatively large returns from undertaking the CTR program described here. The NPVs for the manufacturers and operators are also shown using discount rates that reflect a risk premium appropriate for private sector investments.

Category	Government-Private NPV (millions of $)	Societal NPV (millions of $)
Government/industry research and development	$(435)	$(435)
Industry vehicle production (discounted at 12 percent for private NPV and 7 percent for societal NPV)	$273	$900
Vehicle operations (discounted at 10 percent for private NPV and 7 percent for societal NPV)	$27	$175
Delay reduction	$1,230	$1,230
Infrastructure	0 *	0 *
Total	**N/A**	**$1,860**

* Self-financed from CTR operator fees and passenger ticket taxes and/or user fees.

Figure E10.5-3 Base Case Scenario Summary of Net Present Values in 1995

The large delay reduction benefits projected for CTR were developed using available FAA simulation models. It should be noted that capacity and delay relationships are exponential in nature. After saturation is reached, additional operations cause delays to grow rapidly. Conversely, from the current situation where some airports operate at capacity throughout the day, the reduction in op-

Corridor	Aircraft Delay	Passenger Delay	Environmental	Total Savings
Northeast	$460	$360	$(30)	$790
Midwest	$220	$150	$(20)	$350
West Coast	0	$90	$(10)	$80
Southwest	0	0	$(1)	$(1)
Total	**$680**	**$600**	**$(55)**	**$1,220**

NOTE: discounted at 7 percent through year 2025

Figure E10.5-2 Base Case Scenario Summary of Net Present Value of Delay Reduction and Emissions Increases (In Millions of Dollars)

erations resulting from CTR diversions can produce large estimated reductions in delay.

The delay reduction benefits accrue to all air passengers and aircraft operators at airports where CTR diverts demand for conventional air flights. However, under current institutional arrangements, few if any of these benefits accrue to the operator investing in CTR aircraft, and the operator will not consider these benefits in its investment decisions. If airport landing fees reflected the congestion imposed on other operations, this would raise the cost of conventional air operations at delay-prone airports. If the airport proprietor also operated a vertiport, these additional landing fees could be used to offset part of the vertiport costs. This would provide additional incentives for operators to acquire CTR aircraft.

If the CTR operator could be credited with some of the benefits from delay reduction, it could make the investment in CTRs more attractive. However, this is not likely under current institutional arrangements. Nonetheless, the NPV of the delay reduction benefits are approximately four times the research and development investment needed for CTRs.

E10.6 Economic Analysis

As noted elsewhere in this report, there are considerable risks and uncertainties that must be overcome before there can be a viable CTR system for intercity passenger transportation. However, there are also potentially large benefits in delay reduction in the most congested air travel corridors if a CTR transportation system were developed. It is important not to preclude the CTR alternative from future development. CTR also is of interest because, except for investment in risk reducing technology development and planning of the required infrastructure, all other financial requirements for capital and operations can be met by the private sector. Because CTR is a new transportation system, there is also a need to coordinate actions of the vehicle manufacturers, infrastructure providers, and potential operators.

Using the approach underlying the National Transportation System (NTS) process at the Department of Transportation (DOT), CTR should be evaluated against other intercity transportation choices that also could increase capacity and reduce delay. These include:

- Additional development of new airports and expansion of existing airports.
- Improvements in air traffic control (ATC) system capacity.
- Investment in higher speed rail transportation.
- Demand management strategies, including pricing.

Each alternative should be evaluated for application to specific intercity transportation corridors for economic, environmental, and financial viability. Different solutions may be appropriate depending on the circumstances in each corridor.

E10.7 CTR Development Strategy

Because of the interrelated issues that surround CTR development and introduction, a phased development approach is recommended. In light of the many uncertainties surrounding whether and how these issues can be resolved, the approach also should contain multiple decision points, so that the program can be adjusted or terminated based on the results obtained. If, for example, CTR environmental compatibility cannot be improved by the development of a low-noise rotor, or if such technology cannot be developed at a reasonable cost and without significant negative impacts on vehicle performance, additional investment to develop a CTR system may not be warranted. Similarly, if vertiports cannot be located in areas to attract significant demand for profitable operation, then further investments in infrastructure and vehicle development may not be justified.

E10.8 Intercity Transportation Alternatives Assessment

In order to answer the many questions about the possibility of siting vertiports in attractive locations in terms of passenger demand, a study should be conducted of one specific CTR network, such as in the Midwest or Northeast corridor. This study should be coordinated at the Federal level but should have the active involvement of local planning bodies and airport interests to the extent they are interested in financing operating vertiports. This study would develop demand data on a consistent basis for each metropolitan area within the network at a disaggregate level. In addition, access times and costs to vertiports and existing and planned conventional air and rail facilities should be developed using the same basis of disaggregation. This study also should explicitly consider planned improvements to the conventional air and rail transportation systems likely to be in place when CTRs would enter service. This would provide a basis to evaluate CTR while at the same time considering the alternative modes available to serve the network.

The analysis should consider both public sector investments and returns to the private sector from investing and operating each intercity transportation alternative mode. In addition, the analysis should estimate social benefits and costs, including delay reduction, emissions. This would be a major improvement over the types of analyses that could be conducted for this study. It would permit the completion of an alternative assessment.

E11.0 Further Research and Development Required

E11.1 Government Role in U.S. Civil Aeronautics

E11.1.1 Underlying Economic Theory

The U.S. Government has long recognized that civil aircraft manufacturers will not invest in socially optimal levels of research, technology, and development. This is due to the long lead time required before results can be applied and the likely return earned on research and development investments. A reason for the low returns on investments by the private sector in aeronautics technology is that many aeronautics innovations can be easily imitated so that a company cannot fully appropriate the returns on its investment. Both of these conditions lead to a situation of market failure in which the manufacturer cannot capture a sufficient portion of the potential returns to warrant socially optimal levels of investment. Because of this under-investment, the Federal government has been willing to provide support for basic and applied research, as well as technology development for civil aircraft.

This has been the traditional justification for the National Aeronautics and Space Administration (NASA) aeronautics program. The Government role includes support for basic research, applied research, and technology development for civil aircraft. Government support for technology validation for civil aircraft through demonstrator programs is also appropriate when the private sector does not have sufficient incentives to undertake such activities on its own (reference 24).

Government involvement may be justified economically when social benefits exceed societal costs and in cases where the private sector does not have sufficient economic incentives to invest. This is the case with some aeronautics research and development. The Government, however, operates under a different set of incentives than do private firms. The Government is also able to mitigate the risk of large-scale aeronautics activities through diversification more easily than private sector firms by pooling the risk of several projects. Therefore, the Government uses a lower discount rate than the private sector when evaluating the benefits and costs of technology investment. For these reasons, Government financial support for aeronautics research and development can be justified (reference 25).

E11.1.2 Economic Practice

The role of the U.S. Government in the development of civil aircraft, although vital in content, is limited in scope. Historically, NASA has funded long-lead, high-risk research projects in aeronautics. By contrast, the Department of Defense has played a major role in military aviation technology development. Virtually every technology serving the contemporary civil fleet had its roots in military service experience, including flexible wings, advanced turbojet engines, digital cockpits, fly-by-wire controls, advanced radars, and not incidentally, tiltrotor technology.

NASA and its predecessor, the National Advisory Committee on Aeronautics (NACA), played a key role in two areas, aerodynamics and structures. This agency was at the forefront of airfoil development. In the 1930s and 1940s, 35 to 45 years after the first airplane flight, NACA developed airfoils that are still the standards used by the aircraft industry. A huge amount of airfoil data was researched in NACA wind tunnels and evolved into more complex 'aft-loaded' airfoils. NACA also researched advanced shaping for the lower wing surface that previously had been basically flat. Today, fundamental computer airfoil design codes are NASA funded, because industry does not have

sufficient incentives to invest in this basic research. NASA research assets also include the facilities, especially wind tunnels, and the multi-discipline theoretical aeronautics research. For example, NASA played a key role in the development of supercritical airfoils that have been adopted by both U.S. and foreign aircraft manufacturers.

NASA wrote what is now the industry standard computer program for aircraft structural analysis, NASTRAN. Based on NASA work, the program was later commercialized into a form used universally, with particular application to analysis of composite structures.

For the civil tiltrotor (CTR), a logical continuation of the historical mission of NASA in aerodynamics and airfoil research would be the use of NASA research facilities and funding to define and test a low-noise rotor. Testing scale models of the CTR vehicle itself, like the V-22 before it, would require the use of Langley 16-foot Freon wind tunnel, the only one of its kind. Testing would confirm the aeroelastic characteristics of the CTR, including its freedom from resonant conditions for the combination of an advanced proprotor and thinner, tuned-composite wing through a wide range of flight conditions, including hover/low-speed, conversion and high-speed forward flight. These aspects of rotor development and testing require facilities that the rotorcraft industry cannot afford and the high-risk, long-payoff research that industry is unlikely to fund.

NASA, and its predecessor NACA, have been "jump-starters" for basic research into technologies. NASA has the personnel, facilities, and funding for this type of aeronautics research. Industry bears the responsibility to build on that research base.

E11.1.3 Application to CTR

The efforts by the Administration and Congress to reduce the deficit will increasingly constrain the ability of the Federal government to invest in technology development. The caps on discretionary spending will cause all Federal agencies to limit the start of new programs. In the case of CTR, however, consideration must be given to costs of alternative solutions to meeting the projected increases in demand for intercity transportation. For example, expansion of existing airports is extremely costly. It is becoming increasingly difficult to accommodate growth at key facilities such as Logan Airport in Boston, LaGuardia in New York, National Airport in Washington, D.C., and O'Hare in Chicago. New airports are a potential solution but they cost several billion dollars. In addition, the U.S. has opened only one major new air carrier airport, Denver International, in the last 20 years. Any type of higher speed rail system also will have significant capital costs and may require large subsidies.

The development of CTR infrastructure, including vertiports and air traffic control (ATC) facilities, could be paid for from existing aviation taxes on deposit in the Airport and Airway Trust Fund. While spending of this type is currently constrained, there are several proposals to remove the spending of aviation taxes from the unified budget. If Airport Improvement Program (AIP) levels are constrained in the future, it may be difficult to obtain Federal funds for them. In this case, the financial burden would fall on state and local governments as well as users. To the extent that AIP funds are available, it will require that FAA determine that the development of vertiports is eligible for funding. A rationale for such funding is that vertiports serve to alleviate congestion at other airports, particularly those in the most congested air travel corridors in the U.S. However, there may be resistance to AIP funding of vertiports by some aviation system users.

ATC infrastructure development is likely to require a commitment from FAA to accommodate CTR aircraft in the en-route and terminal environment without affecting conventional aircraft operations. In this way, the addition of CTR flights would represent a net increase in system capacity. None of the research on CTR ATC issues indicates that the changes to the ATC system to accommodate CTR would be particularly difficult or costly (see Chapter E7 of this technical supplement).

CTR has been shown to have the potential for competitive economic performance compared to existing aircraft in certain missions and markets. However, there may be barriers to the private sector adopting CTR technology without some additional stimuli. The literature on the economics of technology indicates that new technology may have difficulty in supplanting an existing technology when the existing technology exhibits increasing returns in comparison to the adoption of new technology. This means that the incremental cost of an existing technology falls as its usage is increased. Aircraft operating economics as well as the costs of airport and ATC infrastructure should be considered. Because all of these are already in place for conventional aircraft operations, additional use of this existing technology is likely to exhibit increasing returns.

Adoption of CTR technology will be characterized by high incremental costs. Not only must the vehicle technology be developed, but there also are needs to modify the ATC system and establish vertiports before CTR can be fully utilized. Therefore, even though the market analysis shows that CTR can be an economic choice for certain missions, such as demand center to demand center transportation or alleviation of congestion at constrained airports, private markets alone may not lead to the development of CTR transportation systems. As a result, the country would forego the use of CTR technology even though it could be economically attractive for certain missions and markets. It will take a cooperative effort among CTR manufacturers, operators and Government to overcome the increasing returns exhibited by conventional aircraft.

The case of short takeoff and landing (STOL) aircraft is an example of a technology that had the potential to supplant existing aircraft for certain missions but that was not adopted by industry. A study by Langford showed that STOL aircraft would produce substantial economic benefits by reducing congestion at existing airports, producing a reduction in delays and allowing additional conventional air service to be offered (reference 26). However, many of the benefits of STOL technology would not necessarily accrue to the airlines who acquired such aircraft. As a result, the existence of these benefits would not affect the price a manufacturer would charge airlines for STOL aircraft.

The introduction of STOL technology would have required that STOL runways be constructed at many airports and that airlines would be willing to initiate such service. Manufacturers also would have had to invest substantial sums to commercialize the results of NASA and Department of Defense research programs into STOL technology. When faced with the alternative of investing to improve existing aircraft, the industry felt that there was too much risk and uncertainty to warrant a launch of a STOL aircraft program.

Government can encourage investment in a new aeronautics innovation by making commitments to develop the technology regardless of the low initial adoption rate. In addition, if firms or individuals have expectations that a new aeronautics innovation will be widely accepted, they may be more likely to adopt the technology or invest in research and development themselves. In summary, if the Government wants industry to adopt superior aeronautics technologies, it may have to invest to develop the technologies to a point where industry can be reasonably sure of their technical and economic performance.

E11.2 Current Government Policy

The current Administration policy on funding technology investments, contained in a recent report (reference 27), states that new investments in technology were needed to: "Invest in applied research and development in fields such as advanced manufacturing, aerospace, biotechnology, and advanced materials." The policy statement recognized that it was necessary to take these actions to strengthen U.S. industrial competitiveness and to create jobs. It noted that Government support may be required when such technologies are critical for long-term economic growth but do not receive adequate support from the private sector, either because returns occur too far in the future or because the level of funding required is too great

for individual firms to bear. It also noted that support was more likely to be provided to those technologies that support the real needs of U.S. business as demonstrated by their willingness to bear part of the cost of such research.

NASA, in implementing the Administration policy, also notes that there are appropriate roles for Government and industry in financing technology development (reference 28). It notes that Federal investment in aeronautical research and technology is a legitimate Government role, because industry will underinvest in high-risk, longer-term technologies. NASA notes that there is a dividing point between what types of technology development should be funded by industry and Government. It identifies that the Government can participate up to the point of system/subsystem model or prototype demonstration after which industry should take over. This essentially leads to sharing of costs between industry and Government over the technology development cycle.

A recent Department of Commerce report shows that the aerospace manufacturing sector is both export-intensive and a source of high-paying employment for U.S. workers (reference 29). Because the U.S. has a significant lead-time advantage in tiltrotor technology, U.S. manufacturers and their employees stand to reap large benefits, if this technology is brought to market.

E11.3 Key to Launch: Government/ Industry Partnership

CTR technology exhibits the same characteristics as other civil aeronautics programs that have been fostered by strategic involvement by Government during the R&D phase. Because CTR implementation requires actions beyond the development of vehicle technology, any such involvement will require coordination at many levels. The following section describes one way in which this could take place.

E11.3.1 Parties and Roles

Actions by a number of entities are required to implement a CTR system for intercity scheduled passenger transportation using 40-passenger aircraft. These entities include CTR manufacturers and operators, NASA, the Federal Aviation Administration (FAA), local planning authorities, airport operators, and the aviation financial community. Coordinating these actions is perhaps the greatest challenge to achieving a CTR transportation system. Aircraft manufacturers will be required to invest well in excess of $1 billion to launch a production program for a 40-passenger CTR. Manufacturers will not undertake such a program until technical and market risks are viewed as manageable. This requires that the development of CTR technology continue to reduce external noise and improve safety. It also requires that operators place launch orders in sufficient quantities to justify manufacturer investment. At the same time, CTR air and ground infrastructure enhancements must be shown to be available on a reasonable timetable for CTR implementation.

Technical risk reduction will require Government action. Government support is crucial because of the type of research and development required and the return on this investment. If manufacturers had to pursue this research and development alone, it is likely the effort would not take place in the near future. At the same time, however, the NASA aeronautics research program is facing an uncertain future and is affected by the pressures to reduce Government spending. Industry may be required to assess the priority of NASA funding for CTR research in light of other NASA investments in aeronautics research. Congressional action will be required if CTR research and development costs are to be paid for with new funding for Government aeronautics programs. The Government will also need to see operator interest as well as progress on the ground and air infrastructure issues before it commits significant new funds for CTR research. FAA support of safety and navigation system research and development for CTR will also be required.

Local planning authorities and airport operators will control general infrastructure development for CTR. Their involvement will be necessary to plan and fund the development of vertiports.

Two types of ground infrastructure development are necessary:

- Initial infrastructure for the CTR start-up phase of operations, involving the expansion of existing heliports and making necessary improvements to accommodate CTRs at existing airports.
- Planning and development of large vertiports that will be needed as the CTR system matures.

Ground infrastructure decisions are inherently local in nature and must take into consideration the economic, environmental, financial, and safety issues raised by CTR operations. Local authorities will need to see that CTR technology can be developed to mitigate adverse environmental impacts. Airport operators could play a key role in financing a mature system of vertiports because CTR provides congestion alleviation benefits at existing airport facilities. On the other hand, the airlines operating at existing airports might oppose vertiport development unless they also operate CTRs.

Airports could make funds available that they receive under the AIP and Passenger Facility Charges (PFC) for vertiport development in order to reduce delays. Even if vertiports could be financed through a combination of AIP funds, PFCs, and landing fees, operators will still need to access capital markets to provide financing. In turn, the financial community will need assurances about the potential economic viability of CTR service.

Developing the air infrastructure for a CTR system will be the responsibility of FAA. Existing studies show that accommodating CTR in the ATC system is feasible and will not present a major cost burden. This research also shows that CTR operations will not have an adverse impact on the ability of the ATC system to handle conventional aircraft operations.

Potential CTR operators will need to see the prospect of profitable operations before investing in these aircraft. This will require that tiltrotor technology be enhanced to produce a safe and reliable civil vehicle. Operators also will require that air and ground infrastructure be developed for initial CTR operations, and that planning and financing for a vertiport network in various corridors is underway. This requires that CTR environmental characteristics allow operations close to passenger origin and destination demand that is a key factor in the economic viability of CTR. Operators are also likely to require that any questions about passenger acceptance of CTR aircraft be resolved prior to investing in new aircraft.

E11.3.2 Opportunities for Cooperation and Cost Sharing

Current policy calls for industry cost sharing in NASA aeronautics research and development programs. The Civil Tiltrotor Development Advisory Committee CTRDAC also found that Government/industry cost sharing should be built into an enhanced CTR research program. The CTRDAC also proposed that the level of industry cost sharing increase as CTR technology moves closer to market introduction. The funds to launch a CTR production program, however, would be entirely the responsibility of industry.

The funds for ground infrastructure planning could come from both local and Federal funds. Planning grant funds for vertiports could be made available under AIP for aviation system planning. Funding for improvement of existing facilities and the development of new vertiports should also come from those who benefit from a CTR transportation system and take into account existing financing mechanisms for aviation infrastructure. The operating costs of these facilities could be paid for with landing fees paid by CTR operators as shown in the CTRDAC financial analysis. In addition, a vertiport would produce some non-aeronautical revenues from automobile parking and from concessions.

Investment funds for vertiports are likely to come from AIP, PFCs, and bond financing secured by landing fee revenues. The CTRDAC recognizes that AIP is likely to undergo a significant restructuring but also recognizes that CTR operations will produce substantial incremental passenger ticket tax revenues even after allowing for the reduction in ticket taxes from diversions from

conventional air operations. As such, vertiports could be made eligible for AIP entitlement funds based on passenger enplanements. However, as noted above, the financial community will need assurances that there is a reasonable prospect for repayment if they lend money for vertiport development. There may be a need for a guarantee of financing for the early phases of vertiport development in order to access the bond market.

E11.3.3 Establish a Public/Private CTR Partnership

As a new transportation system, no existing organization is charged with coordinating activities related to CTR. Because of the many decisions and actions required by diverse parties to implement a CTR transportation system, the CTRDAC recommends the establishment of a public/private partnership to undertake the necessary coordination. This body would also be charged with developing an overall research and implementation plan monitoring the CTR research and development program and with providing recommendations to Congress on whether the CTRDAC proposed schedule or funding for research and development should be adjusted or whether these funds should be redirected or terminated. With the uncertainties and risks surrounding development of a new CTR transportation system, there should be explicit provisions in place to coordinate and redirect the activities of all parties.

The public/private partnership could be structured by FAA. There would be a need to provide the partnership with modest levels of Federal funds of under $1 million per year. It would bring together the activities of FAA, NASA, state and local governments, airport interests, and aircraft manufacturers to coordinate the recommended study of CTR networks and to coordinate CTR research and development. For example, the CTRDAC has recommended that CTR be considered in exploring capacity improvement options for short-haul transportation corridors.

It is expected that state and local governments, airports, and industry would bear their own costs for participating in the partnership.

E11.3.4 CTR as a Capacity Enhancing Option

There are various options available to help meet the growing demand for short-haul transportation in intercity corridors. The Department of Transportation is charged with assessing national transportation system requirements and should include CTR among the options considered to meet national transportation needs. Other options might include:

- Building new airports or expanding existing aviation facilities.
- Improving ATC system capacity.
- Developing new higher speed rail systems.
- Improving highway systems, building expanded roadway capacity, and using intelligent transportation systems.
- Relying on demand management to ration existing capacity.

Several of these alternatives, including CTR, will likely be required to satisfy the growing demand for intercity passenger travel. It is important to find the most cost-effective and environmentally compatible solutions for each transportation corridor. These are not likely to be the same for every U.S. transportation corridor.

E11.3.5 Key Factors Affecting Launch Decision

Infrastructure development and aircraft sales to operators for a new type of aircraft in a new mode of operation introduce a large number of interrelated issues. These issues, at present, represent a major risk to the manufacturer. The overriding concern is that these issues are external and not subject to control of the manufacturer who would have to accept a large measure of the market risk. Figure E11.3.5-1 provides a very limited insight into these issues together with possible means of resolving the issues to reduce program launch risk to an acceptable level. It points to the need for a public/private partnership to jointly resolve the issues through coordinated action.

External Factors	Means of Resolution
Infrastructure Issues	
Location of Vertiports: CTR launch decision cannot bet on profitability of hypothetical sites; must know O&D demand distribution to minimize access time/ maximize market share & operator profit potential. Who will do this? **Operators** - normally buy aircraft based on established routes between existing airports. Manufacturers - cannot incentivize customers with abstract system architecture. **Government** - inclined toward politically acceptable vertiport sites; no regard to user profit potential.	**Resolution:** A "role reversal" of operator & manufacturer may be needed. **Operators** - select vertiport locations to yield acceptable yields using pro-forma routes. Pre-selected sites included in planning; get enabling assist from government authorities. **Government** - needs to be convinced by operator/manufacture that societal benefits for those specific locations are higher than attendant societal costs
Vertiport Acceptance By The Community: Vertiports in numerous locales are needed to reduce launch decision risk. Acceptance depends on economic value added, and transportation need, vs. intrusive characteristics (noise, ground congestion, fear of falling aircraft, etc.) Noise acceptability dominates site selection.	**Resolution:** Locations in high ambient noise locations (industrial regions, over freeways, railroad yards, rivers) are less controversial. Multiple use transportation nodes are good economics & good politics. For most sites, acceptance will require trials with a representative aircraft.
Vertiport Development: Design & construction concurrence with aircraft development is necessary. Operators and manufacturers alike will not proceed without assurances that the process is in motion. Availability of public/private capital must be identified and obligated with date-certain for initial CTR operations.	**Resolution:** A public/private partnership among manufacturer, operator and government would facilitate concurrence between actions of three parties (each of whom has absolute veto power).
Air Traffic Control (ATC): Safe, efficient, profitable CTR system needs ATC based on GPS (global positioning system), adapted to CTR unique operations. The system is needed before aircraft purchase.	**Resolution:** FAA states that this can be done. Detailed planning awaits an immediate need.
Summary: Resolving Infrastructure Issues A public/private partnership would coordinate the process of vertiport sites first, ATC second, operators third, with a concurrent manufacturers launch decision.	
Customer Issues	
Noise Signature: Potential operators expect that vertiport locations will be limited by external noise levels. They will not become customers until this issue is resolved.	**Resolution:** Validation with low noise rotor is crucial to convince potential operators & communities that intrusion is acceptable for the societal benefits gained.
Getting Experience Data: Assuming resolution of infrastructure issues: CTR buyers need data & guarantees on aircraft dispatch reliability, performance, ground and flight safety, & maintainability. No tiltrotor data base currently exists.	**Resolution:** Flight validation data from research aircraft will be limited (reference 46). Prototype demonstrator may be required. Resolution may mean high investment risk to gain lower market risk.

Figure E11.3.1-1 Key Factors Affecting Launch Decision (1 of 2)

External Factors	Means of Resolution
Customer Issues (continued)	
Initial Price/Operating Cost Guarantees: The commercial world views CTR as too expensive to buy and operate. Guarantees will be mandatory. Price: Driven by market, negotiated and guaranteed. Direct operating cost: Guaranteed	**Resolution:** Commercial design criteria plus advanced design & manufacturing technologies must achieve acceptable price. Operating cost must be driven to a minimum by using commercial vs. military design criteria.
Passenger Acceptance: Ride quality, internal noise, safety perception, dislike for small aircraft, and unfamiliar flight profiles are intangibles that passenger will balance against convenience, shorter trip times (reference 47).	**Resolution:** Operator input in design process defines aircraft compatible with contemporary regional aircraft. V-22 operations & prototype demonstrator to increase public knowledge of tiltrotor aircraft
Summary: Resolving customer issues 1. Incorporate the best regional aircraft design practices. 2. Use low noise research rotor vehicle for community noise level validation at selected sites during technical noise measurements. 3. Industry should develop a small civil tiltrotor of 8-10 seat size for use in a variety of missions other than regional air service. A separate civil tiltrotor project would yield valuable operational data and public interest/acceptance years ahead of CTR service use. This is not a diversion from continuing toward a CTR development program during the 2000-2010 period. 4. It may be necessary to develop prototype commercial vehicle for customer and operator flight evaluation; to evaluate potential routes for validating the expectations of time/cost savings to the customers' satisfaction; to identify buyers.	

Figure E11.3.1-1 Key Factors Affecting Launch Decision (2 of 2)

E11.4 Research and Development Options

Before a CTR program launch decision can be made, further research must reduce the uncertainty associated with technical risk and related safety issues of CTR. The CTRDAC Aircraft Subcommittee has identified that more research is needed to perfect:

- A quieter rotor.
- A highly reliable transmission/drive system.
- A cockpit specifically tailored for safe tiltrotor operation.
- Greater contingency engine power for use in emergencies.
- Composite wing, fuselage, and tail design and testing.

The Aircraft Subcommittee has proposed a three-phase program to accomplish these research tasks. Phase A builds on ongoing Government-funded research through NASA in some of these areas. Phase B extends that research to full-scale flight testing while Phase C involves development of a CTR prototype. These recommendations are designed to be the foundation for needed research in several specific areas to reduce technical risk to a reasonable level for civil market application of tiltrotor aircraft.

Phase A adds $220 million to the ongoing $63 million in NASA tiltrotor research. This would move from wind tunnel noise research on model rotors to full-scale rotor testing of an advanced rotor system, with a possible flight test. Additionally, an enhanced reliability drive system, structural and cockpit components, and advanced engine components would be built and tested. All this research must be validated in flight testing. Phase B is a 4-year, $285 million program to build a flight research vehicle derived from a new production V-22 to be used for noise measurements, flying qualities testing, and experiments related to vertiport and air traffic control procedures, including community noise level validation testing.

Although research alone will not determine if a CTR project can be economically viable, it is an essential prerequisite. The CTRDAC Economics Subcommittee has identified significant economic and social benefits that could accrue to the U.S. if a CTR were to be built and put into service by U.S. industry. For reasons stated in this section, research proposed by the Aircraft Subcommittee in Phases A and B represents a shared Government/ industry contribution to the national technical base, consistent with long-standing policy governing NASA aeronautics programs. Phase C, however, covers investments that should be undertaken by the private sector, and this Subcommittee would expect industry to make that investment decision based on their analysis of CTR economic viability at a future point in time.

Examination of the cost sharing between industry and Government should reflect the types of risks involved. While the research and development (R&D) program of $600 million represents one third of the start-up investment, it is designed to address those higher technical risks that are not acceptable for full private sector funding. However, if that hurdle is successfully passed, the remaining industry share would be two thirds of the start-up cost and 100 percent of the risk of market failure (figure E11.4-1). The initial period of high-risk research work with no attendant market risk is under Government sponsorship. During this phase, industry will continue to cost share with Government to some degree (figure E11.4-2).

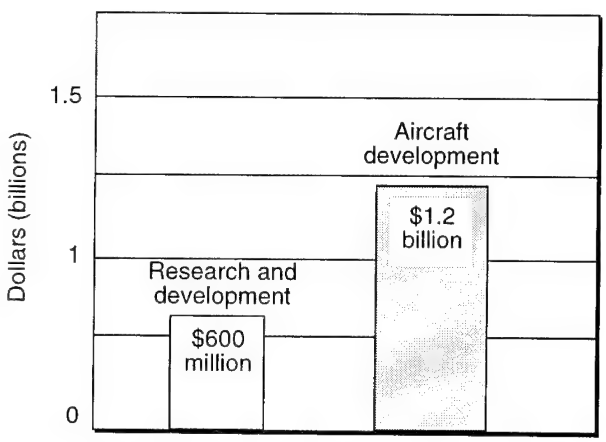


Figure E11.4-1 CTR Startup Investment

Following this research work, industry will be able to consider investing the remaining start-up cost and accepting the very substantial market risk. The $1.2 billion value of industry investment is a preliminary estimate that by all historic evidence is likely to increase. Current market expectations may be either enhanced or diminished according to future developments in air transportation or its alternatives, such as high-speed rail. The $1.2 billion estimate does not include all of the nonrecurring start-up costs, such as inventory buildup, that would contribute to a very significant negative cash flow during the early years of a CTR production program, as shown in Chapter E8 of this technical supplement.

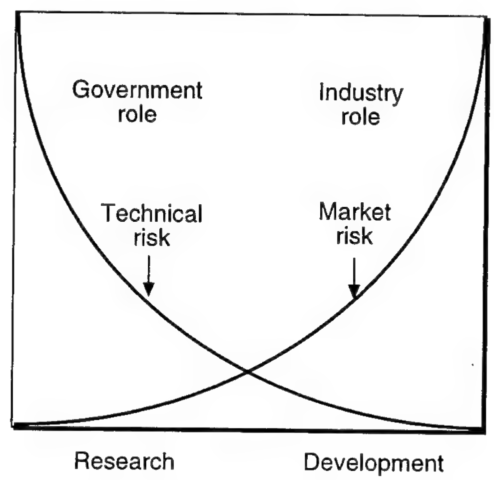


Figure E11.4-2 Government/Industry Sharing of Risks Over Time

E12.0 Findings and Recommendations

E12.1 Introduction

The Economics Subcommittee of the Civil Tiltrotor Development Advisory Committee (CTRDAC) was tasked with investigating the economic issues which surround the introduction of civil tiltrotor (CTR) technology. Work conducted for the Subcommittee investigated a number of issues in order to determine whether a CTR could be commercially viable and what actions would have to be taken in order for a U.S. aircraft manufacturer to launch such a program. These included: (1) examining the economics of CTR vehicles in airline service, (2) the likely demand for a market-responsive CTR vehicle, (3) the development costs needed to launch a commercial CTR production program, (4) the effect of infrastructure cost and development on the size of the market, and (5) whether the operation of the CTR vehicles produced benefits to U.S. society as a whole that could not be captured by either the manufacturer or an airline operator.

The major benefits of CTR technology are to provide more convenient service to passengers, to relieve congestion at major airports, and to maintain the competitiveness of the U.S. aerospace industry. The risks include passenger and community acceptance and the willingness of manufacturers and airlines to pursue CTR development and operation. In addition, because the introduction of CTR services requires the development of a new transportation system with attendant needs for infrastructure development and operators willing to initiate service, there is considerable uncertainty over whether all parties will take necessary action at appropriate times. This, coupled with uncertainty about the performance and acceptability of the CTR vehicle itself, magnifies the risk involved.

E12.2 Key Findings

The following represent the major findings of the CTRDAC Economics Subcommittee:

- CTR service instituted in the first or second decade of the next century could attract sizable ridership in many domestic markets. CTR service is more likely to be financially viable in the Northeast and some Midwest markets due to higher prevailing airfares in these markets. CTR service in markets where existing airfares are low, such as the West Coast and Southwest corridors, would be less financially viable.

- In most markets, CTR fares will likely need to be substantially higher than prevailing airfares to cover projected CTR per-passenger costs due to higher initial acquisition and operating costs. However, because of lower overall travel times using CTR, including advantages in access/egress time, CTR has a competitive total trip time and cost for some passengers which result in CTRs capturing a reasonable share of the market in certain corridors.

- The CTR can produce significant societal benefits when used to alleviate congestion at capacity-constrained airports. However, only a small portion of these benefits accrue to an airline operating CTR. These types of benefits, therefore, may not be a sufficient incentive for airlines to acquire CTRs. Offsetting these benefits, in part, are the increased fuel consumption and engine emissions of the CTR compared to conventional airplanes and other intercity transportation modes. In addition, there may be other strategies which could also alleviate congestion and reduce delays.

- The worldwide demand for 40-passenger CTR aircraft is estimated to range from 1,160 to 1,600 vehicles in the year 2010, including approxi-

mately 400 in the North American market. This is based on a projected selling price of $18.5 million per unit.

- The ability of the CTR to operate in close proximity to the true origins and destinations of air passengers is key to its commercial viability. The development of a low-noise rotor is an important prerequisite for community acceptance of vertiports and CTR operations.

- Vertiport siting is one of the more critical factors in CTR system viability. Community acceptance will be central to developing a CTR transportation infrastructure. Essential considerations include noise reduction to minimize land-use, safe operation and community perception of safe operations, and recognition by the community of the public benefits of CTR.

- Vertiports can be self-financing. This depends greatly, however, on the assumptions made concerning the availability and applicability of Federal airport funding mechanisms, such as the Airport Improvement Program (AIP) and passenger facility charges (PFC). Given a reasonable range of funding scenarios, the level of self-financing attained in a typical year after completing construction of a 27-vertiport system ranged from a profit of $23 million to a loss of $10 million.

- Airplanes operate with well developed air traffic control (ATC) and airport infrastructure and they are a known part of the transportation system. CTRs, on the other hand, require vehicle development and new types of infrastructure such as vertiports. As such, even though there may be substantial benefits to travelers and the nation as a whole from CTR introduction, the market may not adopt this technology in a timely manner without a coordinated public/private effort.

- The manufacturers have estimated a CTR selling price of $17 million to $20 million, based on substantial improvements in manufacturing economies. CTR manufacturing costs are also critical to its commercial viability. At a cost necessary to support a $18.5 million selling price, a CTR program would have a real rate of return on cash flow of 12 percent if approximately 500 units could be sold over 10 years. Over the entire 20-year production period, the program has an net present value (NPV) in 1995 of $273 million when discounted at 12 percent.

- Although the estimated demand for CTR aircraft seems sufficient to satisfy the minimum requirements of manufacturers to pursue CTR development activities, it is unlikely that a U.S. manufacturer would launch a CTR program without further development of the technology because of the technical and market risks involved.

- Operation of CTRs in the four U.S. corridors studied would provide operators with a real rate of return of approximately 11 percent at a CTR selling price of $18.5 million. This has an NPV in 1995 of $27 million when discounted at 10 percent. This estimate is based on the operator revenue and cost relationships assumed in the market analysis. A higher rate of return can be achieved, but at the expense of higher CTR costs, fares, and lower ridership.

- A CTR developed in the U.S. would create jobs and improve the balance of trade. For example, it is estimated that a U.S. CTR could generate approximately 580,000 years of employment over 20 years of production.

- The NPV in 1995 of the social benefits (delay reduction) and social costs (increased emissions) of CTR operations in the four corridors studied total approximately $1.2 billion.

- Energy consumption and emissions do not appear to be discriminators against CTR environmental feasibility but may loom larger for all modes of transportation in the future.

- Overall, when considering all private and social benefits and costs, and how they occur over time, the CTR program has an estimated real rate of return of as much as 16 percent.

- The overall returns of a CTR program are comprised of elements shown in figure E12.2-1.

Category	Government-Private NPV (millions of $)	Societal NPV (millions of $)
Government/industry research and development	$(435)	$(435)
Industry vehicle production (discounted at 12 percent for private NPV and 7 percent for societal NPV)	$273	$900
Vehicle operations (discounted at 10 percent for private NPV and 7 percent for societal NPV)	$27	$175
Delay reduction	$1,230	$1,230
Infrastructure	0 *	0 *
Total	**N/A**	**$1,860**

* Self-financed from CTR operator fees and passenger ticket taxes and/or user fees.

Figure E12.2-1 Base Case Scenario Summary of Net Present Values in 1995

E12.3 Risks and Uncertainties

There are considerable risks and uncertainties inherent in evaluating the likely economic and social performance of any new transportation mode. In particular, the CTRDAC Economics Subcommittee was tasked to evaluate the demand for CTR vehicles in the year 2010. The analysis assumes that any start-up difficulties and risks could be successfully managed. In addition, the analysis assumes that base values can be achieved for a number of important parameters, most importantly, the structure and performance of the airline industry in the future. The key uncertainties include:

- *Future Airfares*

The demand for CTR service is affected by the levels of future airfares.

- *Airline Competitive Response*

The way in which airlines react to the introduction of CTR services will also affect the commercial viability of CTR service, especially in the early years just after introduction.

- *Vertiport Siting*

The ability to locate vertiports close to passenger ultimate origin and destination points is a key to its competitive advantage over other modes.

- *Start-Up Costs*

While the analysis in Chapter E11 of this technical supplement includes provisions for start-up costs, it was not possible to develop precise estimates of these costs.

- *Future Air Travel Demand*

The demand projections for future CTR service and the level of delay in the conventional air transportation system both depend on the growth rate in future air travel.

- *CTR Operational Efficiency*

There are no data based on service experience about the actual operating cost performance of CTRs.

- *CTR Production Costs*

There is no history of manufacturing costs for CTR vehicles in serial production.

- *ATC Accommodation*

The analysis assumes that CTRs can be accommodated without major impact in the future ATC system.

- *Passenger Acceptance*

It is not known to what extent passengers will accept the use of CTR vehicles for scheduled commercial air transportation.

- *Safety*

There is a limited base of information on tiltrotor safety or how this will affect passenger demand and operator decisions to purchase CTRs.

- *Risk Compounding*

CTR commercial success is particularly vulnerable to failure due to risk compounding. "Success" requires that a large number of unknowns be resolved in favor of CTR, while a negative resolution of only a few unknowns could result in failure.

Many of the above risks have been examined in sensitivity analyses conducted as part of the CTR-DAC effort. Some of these risks are of a threshold nature which must be resolved satisfactorily for the successful introduction of CTRs into commercial service. Ultimately, many of these risks and uncertainties can only be resolved after introduction of CTR service.

E12.4 Recommendations

The CTRDAC Economics Subcommittee recommendations include:

- A Government-supported research and development program for technical risk reduction focused on environmental and safety areas should be pursued. Industry cost sharing should be considered where appropriate. Milestones should be built into the program to redirect or terminate the program if intermediate results so warrant.

- Work should begin on site identification and preliminary planning for vertiports. This includes planning for modifications to existing facilities, including select airports and heliports, for start-up as well as development planning of new vertiport facilities for a mature CTR network system.

- A public/private partnership should be formed for the implementation of CTR. Numerous issues require simultaneous decisions. No one party can make all the necessary decisions and implement CTR alone because no one party controls all the resources involved.

- A CTR network study involving manufacturers, the Federal Aviation Administration (FAA), and local governments should be developed for one promising U.S. corridor. The study should include identifying specific vertiport sites to determine operational requirements and improve demand analysis. A zone-specific passenger origin/destination travel demand analysis should be preformed incorporating travel time sensitivity. This analysis must use data comparable across metropolitan areas. Finally, the active cooperation of local planning bodies must be sought to acquire necessary input data for vertiports locations, CTR operations planning, and general issues related to community acceptance of CTR.

- The large potential of CTR for reducing transportation delays justifies consideration of CTR as an alternative to other ways of achieving the same benefits, such as expanding or building new airports, improving air traffic control, developing higher speed rail systems, expanding or building new highways, developing intelligent highway vehicle systems, or implementing demand management (i.e. congestion) pricing of existing transportation systems.

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Acronyms

AAIA	Airport and Airway Improvement Act
AC	advisory circular
ACIP	Airport Capital Improvement Program
ACT	Advanced Compsite Technology
ADS	automatic dependent surveillance
AFCS	automatic flight control system
AIP	Airport Improvement Program
ALUC	Airport Land-use Commission
ARFF	aircraft rescue and fire fighting
ARTCC	air route traffic control center
ASM	available seat mile
ASOS	automated surface observation system
ASP	Aviation System Plan
AST	Advanced Subsonic Technology
ATC	air traffic control
BIT	built-in test
BOS	Boston Logan Airport
BVI	Blade Vortex Interaction
CAAA	Clean Air Act Amendments of 1991
CATIA	Computer Aided Three-Dimensional Interactive
CBD	central business district
CFR	Code of Federal Regulations
CNS	communication, navigation, and surveillance
CO	carbon monoxide
CO_2	carbon dioxide
CRA	Charles River Associates Inc.
CRAF	Civil Reserve Aircraft Fleet
CRDA	Cooperative Research and Development Agreement
CTR	civil tiltrotor
CTRDAC	Civil Tiltrotor Development Advisory Committee
dB	decibel
dBA	A-weighted decibels
DCA	Washington, D.C. National Airport
DER	designated engineering representatives
DFW	Dallas/Ft. Worth Airport
DNL	day-night sound level
DoD	Department of Defense
DOT	Department of Transportation

EIS	environmental impact statement
EMD	engineering, manufacturing, and development
EMS	emergency medical service
EPA	Environmental Protection Agency
ETOPS	Extended Twin-Engine Over Water Operations
EUROFAR	European Future Advanced Rotorcraft
FAA	Federal Aviation Administration
FAAO	Federal Aviation Administration Order
FAR	Federal Aviation Regulation
FATO	final approach and takeoff area
FBL	fly-by-light
FBW	fly-by-wire
FCS	flight control system
FEMA	Federal Emergency Management Agency
FHA	Federal Housing Authority
FHWA	Federal Highway Administration
FMEA	failure modes and effects analysis
FOQA	flight operations and quality assurance
FPT	full price of travel
FRA	Federal Railroad Administration
FSD	full-scale development
FTA	Federal Transit Administration (previously the Urban Mass Transportation Administration)
FY	fiscal year
G&A	general and administrative
GA	general aviation
GAO	General Accounting Office
GDP	gross domestic product
GFE	Government-furnished equipment
GPS	global positioning system
HC	hydrocarbons
HDR	high density rule
HHC	Higher Harmonic Control
HNM	Helicopter Noise Model
HSAC	Helicopter Safety Advisory Conference
HSDS	hydraulic screw drive system
HSGT	high-speed ground transportation
HSR	high-speed rail
HUD	Housing and Urban Development
HUMS	Health and Usage Monitoring Systems
IAD	Washington, D.C. Dulles Airport
ICAO	International Civil Aviation Organization
ICDS	interconnect drive shaft
IFR	instrument flight rules
IHPTET	integrated high performance turbine engine technology
IRR	internal rate of return

ISA	International Standard Atmosphere
ISTEA	Intermodal Surface Transportation Efficiency Act
JFK	Kennedy Airport
LAAS	Local Area Augmentation System
LGA	LaGuardia Airport
MC/BFE	Master Changes/Buyer Furnished Equipment
MITI	Ministry of International Trade & Industry
MPO	metropolitan planning organization
MSA	Metropolitan Statistical Area
MTBF	mean time between failures
NACA	National Advisory Committee on Aeronautics
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASPAC	National Airspace System Performance Analysis Capability
NCA	Noise Control Act
NEC	Northeast Corridor
NFPA	National Fire Protection Association
NOX	nitrogen oxide
NPIAS	National Plan of Integrated Airport Systems
NPTS	National Personal Transportation Survey
NPV	net present value
NRS	national resource specialist
NTS	National Transportation System
NTSB	National Transportation Safety Board
O&M	operation and maintenance
O/D	origin/destination
OAG	Official Airline Guide
OEI	one engine inoperative
OMB	Office of Management and Budget
ORD	O'Hare Airport
PANYNJ	Port Authority of New York and New Jersey
PEEK	polyether-ether-ketone
PFC	passenger facility charge
PFCS	primary flight control system
POL	petroleum, oil, and lubrication
PSA	Pacific Southwest Airlines
R&D	research and development
RPM	revenue passenger mile
RPM	revolutions per minute
RSPA	Research and Special Programs Administration
SCT	Systems Control Technology
SHP	shaft horsepower
SLL	structural loads limiting
SMS	Simulation Modeling System
STOL	short takeoff and landing
TERPS	terminal instrument procedures

TLOF	touchdown lift-off surface
TPC	thermoplastic core
VA	Veterans Affairs
VDTR	variable diameter tiltrotor
VFR	visual flight rules
VMS	Vertical Motion Simulator
VMT	vehicle miles traveled
VNTSC	Volpe Transportation System Center
VSLED	vibration structural life and engine diagnostics
VSTOL	vertical/short takeoff and landing
VTOL	vertical/short takeoff and landing
WAAS	Wide Area Augmentation System

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